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Phosphate Adsorption and Desorption by the Sediment in the Chikugo River Estuary, Japan

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Experiments were made on the effects of temperature, pH and salinity on phosphate adsorption and desorption by the oxidized surface sediment of the turbid Chikugo River estuary. The adsorption and desorption reactions were rapid with equilibrium being reached within 2–4 h. Also the rise of temperature from the in situ temperature caused the gradual desorption of phosphate after 1 h. Maximum adsorption and minimum desorption were found within the range of salinity 1.7–3.4. Equilibrium phosphate concentrations by the sediment in diluted sea water and in sea water were 2–3μg·at l^{-1} and above 5μg·at l^{-1}, respectively. These suggest that the adsorption of phosphate may be predominant in the low salinity region of the estuary. Conversely, only the desorption of phosphate may take place in the high salinity region. The buffering of phosphate by the resuspended sediments is one of the main factors that regulate the dissolved phosphate concentration, at least during spring tide.

In turbid estuaries, phosphate concentrations are often relatively constant over the wide range of salinity.[1,2] These non-conservative behaviours of phoshate were attributed primarily to the non-biological buffering reaction by suspended or bottom sediments.[3] In well mixed or partially mixed estuaries, the resuspended sediment is subjected to the drastic environmental changes in salinity, pH and temperature during the semidiurnal tidal excursion especially in the spring tide.[4,5] Consequently, the effects of environmental factors on the non-biological phosphate adsorption or desorption by the resuspended sediment must be elucidated in order to determine the behaviour of phosphate in the estuary.

In many of the laboratory experiments so far conducted, radio tracer techniques were used to investigate the effects of environmental factors on the adsorption or removal of dissolved phosphate. In this experiment the desorption of already adsorbed phosphate on the sediments is examined to further understand the nature of the buffer system. The purpose of this study is to gain more insight into the phosphate adsorption and desorption reactions through the laboratory experiments using the sediment samples collected from the bottom surface of the Chikugo River estuary.

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MATERIALS AND METHOD

The Chikugo River is the largest river draining the Ariake Bay in Kyushu Island. The discharge average for a 30 year period is 112 $m^3 \cdot s^{-1}$ and the drainage area is 2860 km^2. As described by SHIROTA and TANAKA,[4] the Chikugo River estuary is generally considered to be a well mixed estuary with the highest tidal amplitude of as high as 5 m. The results obtained during a series of detailed surveys of phosphate distribution in the Chikugo River estuary also provided evidences of non-biological reactivity of dissolved phosphate with the tidal current-induced resus-

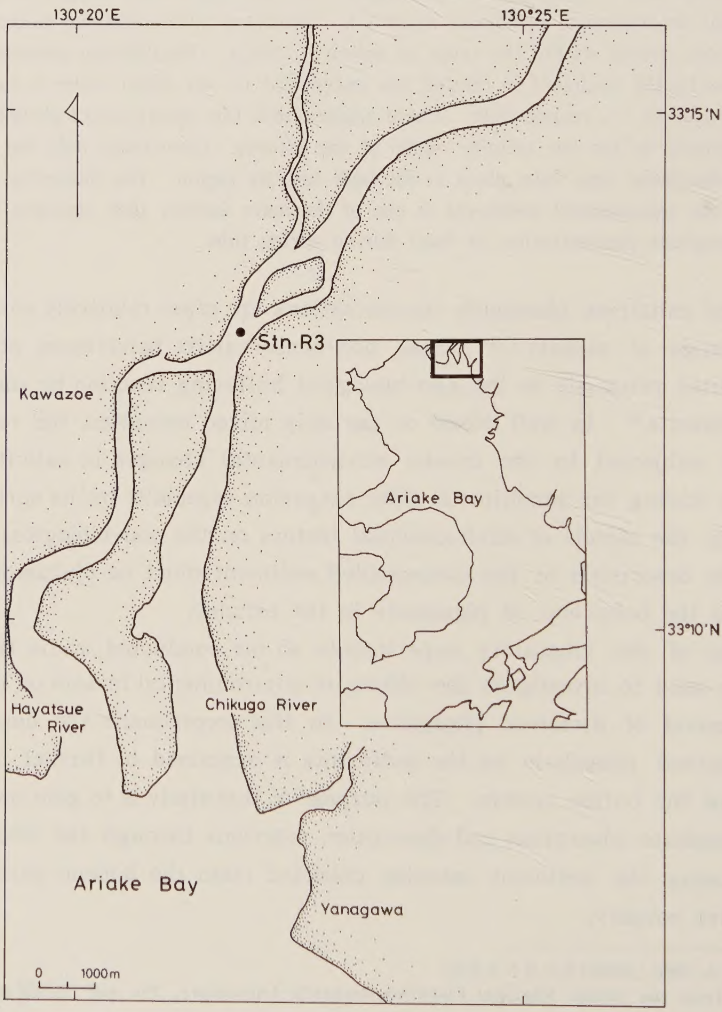


Fig. 1. Map of the Ariake Bay and the Chikugo River estuary showing the sampling station.

pension of bottom sediments.[6] During spring tide, the tidal current-induced resuspension of bottom sediments forms a turbidity maximum (100–4,000 mg l^{-1}) which is transfered landward or seaward depending on the semidiurnal tides by advection. The suspended bottom sediments in the estuary are composed of montmorillonite and illite.[7] For the detailed description of the Ariake bay and the Chikugo River see INOUE.[8]

Because the sampling of large quantities of suspended sediments from the water is not practical, the settled surface sediment was sampled at Stn. R3 (Fig. 1) at neap tide. The Stn. R3 is located in the River at the landward reach of haline water. The thickness of the oxidized surface layer was up to several centimeters. In the spring tide, the surface layer of such oxidized sediment is in suspension within the turbid water.[9] Sediments were collected with an Ekman-Berge sampler in October and December 1985. The near bottom salinity and temperature at the two sampling times were 5.2, 20.2℃ and 6.8, 11.2℃, respectively. After the removal of overlaying water with a siphon, the oxidized layer (0–1 cm) of the sediment was carefully scraped.

In the laboratory, samples were centrifuged (4,000 rpm, 15 min.) and the supernatants were removed for interstitial phosphate determination. The dry weight of subsample was measured after drying at 105℃ for 4 h. The remaining solids were homogenized and 0.5 g or 2.5 g (wet wt.) of the sediment were shaken with a multiple shaker in known amounts of sea water. Phosphate-free sea water from the Kuroshio (Sal.=34.4) was diluted with distilled water. The ratios of sea water volume to the total solution were adjusted to 1 (sea water), 1/2, 1/4, 1/10, 1/20, 1/50, and 0 (distilled water). Phosphate spikes were made from KH_2PO_4 stock solution, to give final phosphate concentrations in the range from 0 to 10 μg·at l^{-1}, and NaOH or HCl solution was used to adjust pH. The amount of interstitial phosphate introduced to the solution is negligible, because the concentrations of interstitial phosphate in the sediment samples were as low as 2.6–2.9 μg·at l^{-1}.

The initial experiments were made in order to determine the reaction time required for the phosphate adsorption or desorption reaction to reach equilibrium. 2.5 g (wet wt.) of the sediment (sampled in 1985 Oct.) was shaken with 100 ml of sea water solution (1/2 sea water). The experiments were conducted under the following conditions: temperature 20℃ (in situ temperature), initial phosphate concentration of 0 and 10 μg·at l^{-1}, initial pH 7.4–7.5. Duplicate groups of sediment suspensions were prepared and $HgCl_2$ was added to one group (final concentration 0.01%). Aliquots of the reacting suspensions were withdrawn on each sampling time. Sediments were separated from the suspensions by centrifugation and filteration using 0.45 μm Millipore filters.

The effect of temperature on the adsorption and desorption of phosphate was

measured at 10℃ (in situ temperature) and at 30℃ using the sediments collected in Dec. 1985. The experimental condition is the same as the previous experiment.

To evaluate the effects of pH and salinity on phosphate adsorption and desorption, 0.5 g (wet wt.) of the sediment (sampled in 1985 Dec.) was made to react with 20 ml of sea water (SW) or diluted sea water for 4 h (initial phosphate concentration; 0 and 10 μg·at l^{-1}) at in situ temperature (10℃).

The amounts of phosphate adsorbed or desorbed were calculated from the differences between the initial and the final phosphate concentrations on the dry weight basis. The filtrates were analyzed for the phosphate with the method of STRICKLAND and PARSONS.[10]

All the experiments described above were completed within a week after the sampling times, when the sediments were stored at 4℃. The pH was monitored before and after the experiments, the changes being normally within the range of ±0.1.

RESULTS AND DISCUSSION

1. Kinetics and the effect of temperature

The results are presented in Fig. 2 and show that the adsorption and desorption reactions take place rapidly with equilibrium being reached within 2-4 h. The time scale for the adsorption was similar to that observed for the adsorption in clay minerals.[11]

The sediment adsorbed more phosphate and desorbed less phosphate in diluted sea water. The effects of the ionic strength is discussed in more detail in the following experiment. Poisoning with $HgCl_2$ resulted in higher phosphate concentrations suggesting the biological uptake of phosphate in the absence of $HgCl_2$. A large quantity of phytoplankton pigments was contained in the resuspended sediments in the turbid water area, however, the effect of biological uptake was small relative to that of non-biological exchange. For the purpose of elucidating non-biological exchange process itself, $HgCl_2$ was added to all suspensions in the following experiments.

Although the equilibrium was attained within 2-4 h at in situ temperature (10℃) as in the previous experiments, the reactions at 30℃ did not reach equilibrium until 8 h later (Fig. 3). At 30℃ more phosphate was adsorbed within 1 h than at 10℃, and the concentration of phosphate in the solution increased gradually after 1 h on the both adsorption and desorption experiments. These results show that there are at least two kinds of separate reactions involved in the adsorption and desorption system. It appears that the rise from the in situ temperature affects both on the initial rapid adsorption (within 1 h) and slower desorption. There was

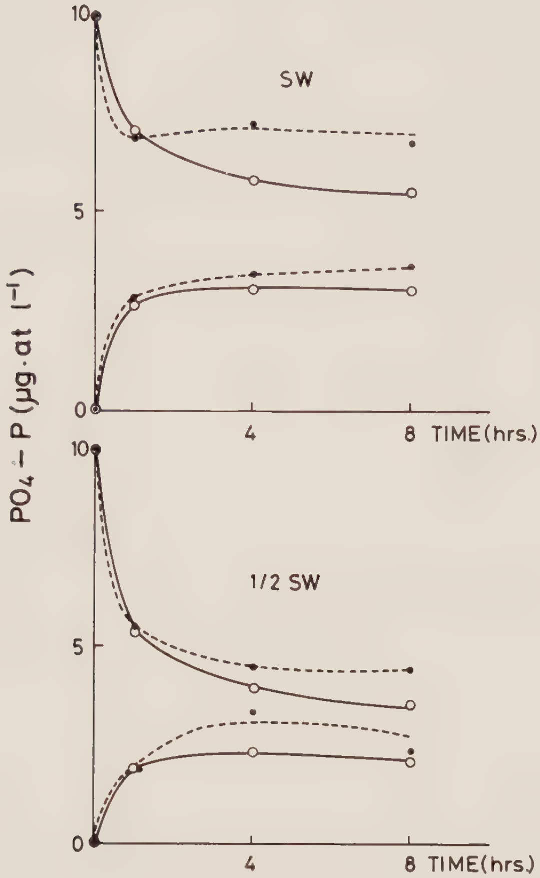


Fig. 2. Kinetics of phosphate adsorption and desorption in sea water (SW) and diluted sea water (1/2 SW). Dotted lines represent samples poisoned with $HgCl_2$.

no marked difference between the equilibrium phosphate concentrations at the in situ temperatures of 10℃ (Fig. 3) and 20℃ (Fig. 2). In contrast to these observations, CARRITT and GOODGAL[12] found increasing phosphate removal with rise in temperature. As noted by POMEROY *et al.*,[13] such discrepancy may be explained by the biological effects during the reactions, which are sensitive to temperature change.

2. Effect of pH

The effects of pH on phosphate adsorption and desorption of the sediment in sea water and 1/2 sea water are illustrated in Fig. 4.

With increase in pH, adsorbed phosphate decreased and desorbed phosphate increased. Adsorption of phosphate by the sediment as a function of pH agreed well with the pH response of sediments obtained by CARRITT and GOODGAL.[12] In

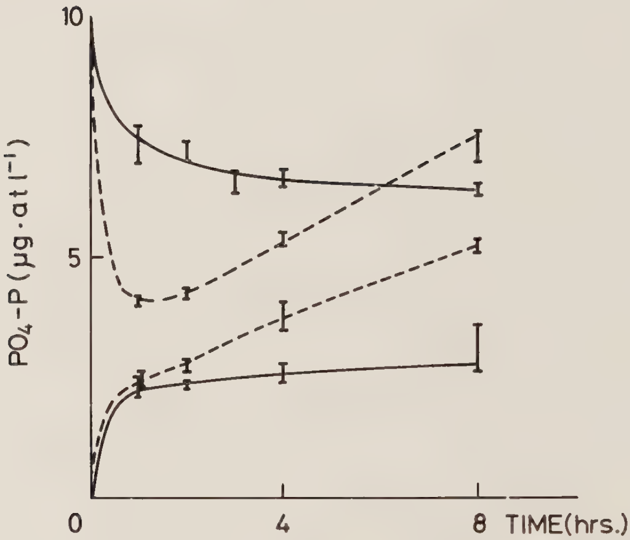


Fig. 3. Effect of temperature on the kinetics of phosphate adsorption and desorption in sea water. Smooth lines represent samples at 10°C (in situ temperature) and dotted line at 30°C. Vertical bars represent the scatters of the duplicate samples.

the final pH ranging from 6.5 to 7.5, there were no differences between the amounts of adsorbed or desorbed phosphate in sea water and those of 1/2 sea water. With an increase in pH, the differences increased so that more phosphate was desorbed and less adsorbed in sea water than in 1/2 sea water. These results indicate that in regions of high salinity, the desorption of phosphate is accelerated and the adsorption suppressed.

3. Effect of salinity

The experimental conditions are the same as the previous experiments. The results are summarized in Fig. 5. Although no pH adjustment was conducted, the final pH was nearly constant ranging from 6.8 to 7.3 except in the case of sea water (pH 7.5-7.6). With the decrease in the ratio of sea water to the total volume of the solution, the amount of desorbed phosphate decreased and adsorbed phosphate increased. Below the ratio of 1/20, adsorbed phosphate decreased and desorbed phosphate increased, forming a maximum of adsorbed phosphate and a minimum of desorbed phosphate between 1/20 sea water (Sal.=1.7) and 1/10 sea water (Sal.=3.4).

The gradual decrease of adsorbed phosphate with increase in salinity may be due to the blocking of anion exchange sites by competing anions (Cl^{-1} and SO_4^{2-})

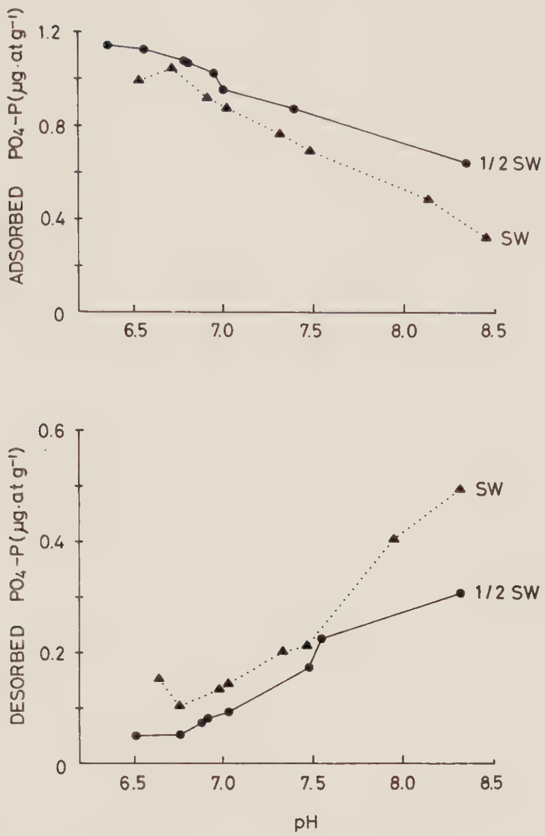


Fig. 4. Effect of pH on the adsorption (upper) and desorption (lower) of phosphate in sea water (SW) and 1/2 sea water (1/2 SW).

as discussed by LISS.[3] The mutual flocculation of phosphate with colloidal substances occurs in the presence of trace amounts of salt.[7,14] Thus, the lower value of adsorbed phosphate and higher value of desorbed phosphate in distilled water, may be caused by the de-flocculation of colloidal substances and its subsequent release of phosphate.

However, CARRITT and GOODGAL[12] reported the highest value of adsorbed phosphate in salinity 0‰. They explained the increase of adsorption with decrease of salinity by the reduction of surface area available for adsorption by the aggregation of particles in high salinity waters. This was not observed in our experiment. This discrepancy may be explained by their use of radio tracer, which cannot track the desorption of originally adsorbed phosphate.

With clay minerals and iron oxyhydroxides, in contrast, there is no consistent tendency as to the effect of ionic strength on the phosphate adsorption.[11,15] On

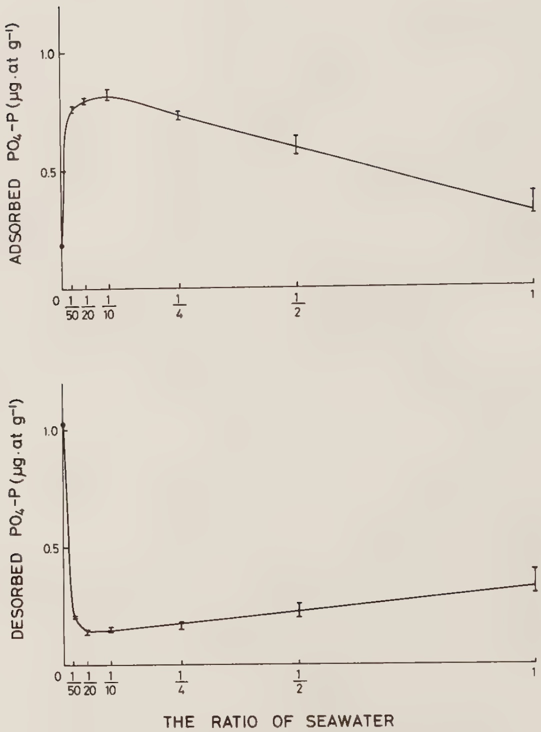


Fig. 5. Variations of phosphate adsorption (upper) and desorption (lower) against the ratio of sea water to the total solution. Vertical bars represent the scatters of the duplicate samples.

the other hand, the removal of phosphate by flocculation with dissolved organic matter increases with the increase in salinity to 15–20‰.[16] It seems that these apparent maximum and minimum in Fig. 5 were caused by the combined effects of salinity and pH on each individual adsorbant in the sediment.

4. Phosphate buffering capacity

Phosphate adsorption and desorption were examined in order to obtain 1) the true equilibrium phosphate concentration toward which natural sediment-water suspensions tend to equilibrate (TEPC), 2) the amount of already adsorbed phosphate on the sediments, and 3) its buffering capacity.

The sediment sampled in Oct. 1985 was made to react with known amounts of phosphate-free or phosphate-spiked solutions (sea water and 1/2 sea water; initial phosphate concentration 0, 2.5, 5, 7.5, and 10 μg·at l^{-1} for 4 h at in situ temperature (20℃). The amount of dissolved phosphate adsorbed or desorbed was plotted against the equilibrium phosphate concentration (Fig. 6).

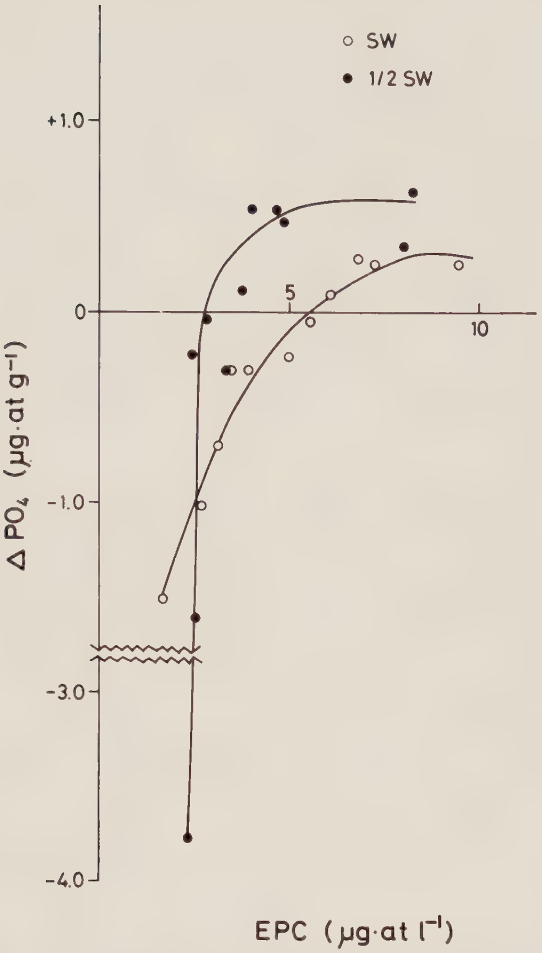


Fig. 6. Phosphate adsorption and desorption on the sediments in sea water (SW) and 1/2 sea water (1/2 SW).

With increase in the equilibrium phosphate concentration (EPC) the amount of adsorbed phosphate increased. However, the values at 1/2 SW and SW became stationary at about 0.5 μg·at g^{-1} and 0.25 μg·at g,$^{-1}$ respectively. On the other hand, the phosphate concentrations where neither adsorption nor desorption take place (TEPC) decreased with decrease in the ratio of sea water. TEPC at the 1/2 SW and SW were 2–3 μg·at l^{-1} and above 5 μg·at l^{-1}, respectively. According to POMEROY *et al.*,[13] the EPC was within the range of 0.7–1.6 μg·at l^{-1}. This range is much smaller than that of this study. However, comparisons cannot be drawn because neither the concentration of sediments nor the salinity of the solution in the experimental suspension is cited in their report.

TEPC at 1/2 SW was found to lie in the range of relatively constant concen-

trations of dissolved phosphate in the Chikugo River estuary.[6] Below these concentrations the phosphate desorption took place, and the total amount of phosphate desorbed at 1/2 SW and SW reached up to 3.8 μg·at g^{-1} and 1.5 μg·at g^{-1}, respectively. Since the EPC values are still above 2 μg·at l^{-1}, the amount of already adsorbed phosphate will be much higher than such values. Therefore, liner models for adsorption such as LANGMUIR and FREUNDLICH isotherms can not be used to describe the process of adsorption. However, the observed data shows the possibility of LANGMUIR isotherm as in the case of clay minerals.[11]

The total adsorption capacity will be more than 4 μg·at g^{-1}. In general, the concentration of phosphate in the high salinity region of the estuary is below 2 μg·at l^{-1}. Hence, only the desorption of phosphate may take place in the high salinity region of the estuary.

From these results, the non-biological behaviours of phosphate in the estuary can be summarized as follows. First, dissolved phosphate is removed by mutual flocculation with colloidal substances in the extremely low salinity region. Secondly, the phosphate concentration is buffered by the resuspended sediment in the turbid water in the low salinity region. Finally, the desorption of phosphate takes place by the increase of equilibrium phosphate concentration in the high salinity and low turbidity region.

The total amount of exchangeable phosphate reaches up to 4 μg·at of phosphate per gram of dry sediment. In the turbid water area of the Chikugo river estuary, the concentration of resuspended sediments is as high as 2–4 g·l^{-1} during the spring tide.[4] Consequently, the buffering of phosphate by the resuspended sediments will be one of the main factors to regulate the dissolved phosphate concentration. Moreover the transportation of the suspended sediment with adsorbed phosphate into the sea and its desorption is one of the main source of phosphate supply to the sea.

ACKNOWLEDGEMENT

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筑後川河口域における底泥によるリン酸塩の吸着と溶脱

田　中　勝　久

抄　録

筑後川河口域における酸化表層泥によるリン酸塩の吸着と溶脱作用に対する温度，pH および塩分の影響を，室内実験によって検討した。吸着，溶脱反応は急速で約2-4時間後には平衡に達した。また，現場温度より高い温度では1時間後から次第にリン酸塩が溶脱した。塩分1.7-3.4で吸着反応は極大，溶脱反応は極小となった。平衡リン酸塩濃度は希釈海水で 2-3μg·at l^{-1}，海水で 5μg·at l^{-1} 以上であり，これらのことから，河口の低塩分域ではおもに吸着反応が，反対に高塩分域では溶脱反応がおこることが示唆された。底泥のリン酸塩濃度緩衝作用は，少なくとも大潮時には河口域の溶存リン酸塩濃度の重要な調節要因となろう。

プランクトンネットの開口比が濾過効率と採集量に及ぼす影響

小笹　悦二*・木元　克則*

Effect of the Open Area Ratio of the Plankton Net on the Filtering Rate and Yield

Etsuji KOZASA* and Katsunori KIMOTO*

Experiments were carried out at sea to investigate the effect of the open area ratio of plankton net on the filtration efficiency and yield, using six types of plankton nets having the same mouth area and mesh size but different filtering ratios.

Clogging of the plankton net decreases the sampling efficiency. The highest filtration efficiency was attained when the plankton net had an open area ratio R=7.2, and the efficiency decreased either above or below this value. The yield of plankton per one haul was proportional to the towing time. On the contrary, the yield of plankton did not increase with towing velocity increased from 1.5 to 3.0 knot. The yield of plankton collected from a unit volume of water filtered was less by the nets having large open area ratio than by those having small open area ratio. This difference was presumably due to the fact that the net having small open area ratio was much clogged by phytoplankton and other matter and accumulated more small organisms in the sea. The most suitable sampling conditions and net design were referred.

プランクトンを採集する方法の一つにプランクトンネット（以下ネットと称する）採集法がある．この場合対象生物の大きさによってネットの口径と網地を選択し，さらに設定した濾過すべき水量（以下希望濾水量と称する）[1~3] を最低持続濾水率（通常85%とする）で目詰りなく濾過する必要がある．このため，沿岸水域で使用するネットの開口比（R：網口面積に対する網地開孔面積の比）を Smith ら[4] の式(1)で求める．

$$\log_{10} R = 0.38 \log_{10}(Wo/M) - 0.17 \quad \cdots\cdots(1)$$

ただし　Wo：希望濾水量　M：網口面積

この式により得られた開口比と対象生物の大きさによって決めたネットの口径，網地を用いて，採集水域に適したネットを作製する．

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これまで多くのプランクトン研究者によって，ネットに関する研究が行われ，特に流体力学的な検討が，Tranter and Smith[5]，Tranter and Heron[6] および元田[7] らによって行なわれた．また McGowan and Brown[2] によって理想的なネットの形状としてボンゴネットが報告されている．

曳網距離(曳網時間)の延長にともないネットの網目が詰り，濾過効率は次第に低下する．開口比が小さいネットほど目詰りは早く起り，濾過効率の低下と網口からの水の吐き出しが多くなり，曳網距離と得られたプランクトン量が比例しなくなる場合がある．[3,4,8] さらに曳網距離を延長すると，網地の目詰りがひどくなり採集生物に損傷を及ぼすことが明らかにされている*．わが国で一般に使用されている北太平洋標準ネット（$R \doteqdot 3.7$），丸中ネット（$R=2.4$）および丸特Aネット（$R=1.7$）等の開口比はボンゴネット（$R=6.8$）のそれに比べてはるかに小さく，そのためこれらのネットは曳網中に濾過効率の低下が著しいものと推定される．そこで本報告ではボンゴネットの開口比を基準として，これより開口比の小さい $R=2.0$ からその倍の $R=15.0$ までの6種類のネットを作製し，同一条件下において曳網した場合にネット開口比の相違が濾水量と得られたプランクトン量に及ぼす影響について，沿岸水域で採集実験を行った．その際の濾水量と得られた動物プランクトンの湿重量を用いて，濾過効率が大きくしかも採集効率の高いネットの開口比と，またその採集方法について検討した．

方　　法

1984年8月24日，28日および31日に長崎港外(32°45′N，129°45′E）において，小型船（3.6トン）を用いて1.5ノットと3.0ノットの速度で，1分，3分および6分間曳網を各5回繰り返し採集を行った．採集に供したネットは口径30cm，網地の網目幅335μm（nytal® 52GG）で，Table 1 に示した開口比（R）の異なるA，B，C，D，EおよびFの6種類（$R=2.0\sim15.0$）である．

採集には直径60cmのプランクトンネットの枠に前記のネットをⅠ（A，B，CおよびDネット）とⅡ（D，EおよびFネット）の2つの組合せで等間隔に取付け，これらを船尾から延ばした長さ20mのロープの先端に取付けて曳網した．なお，曳網中に網口が一定水深になるように曳網用ロープの先端部に浮子（ロープの長さ2m）と錘（2kg）を付けた．各ネットには流量計（General Oceanic Inc. 製2030型）を用いて濾水量を求めた．所定時間曳網後に船を止めてネットを引き上げ，これらを充分に洗って採集物を集め中性ホルマリンで固定した．得られた210本の試料は研究室で動物プランクトン（稚仔魚とサルパ，クラゲ類を除外）をグラスファイバーフィルター（Whatman® GF/C 直径47mm）上に吸引捕集し，湿重量を測定した．採集条件別に5試料（湿重量）の最大値と最小値を除外し，残る3試料の平均湿重量(以下採集量と称する)を用いて以下の検討を行った．ここで曳網距離（D）は次式(2)で求めた．

Table 1. ネットの仕様
Specifications of nets

Net	Diameter		Length of	Lenght of	Open area	Water volume accepted
	mouth	cod end	cylindric part	Conical part	ratio	85% at 1 haul
A	30cm	6 cm	13cm	30cm	2.0	1.23m³
B	〃	〃	23	56	3.5	5.35
C	〃	〃	33	81	5.0	13.68
D	〃	〃	70	80	7.2	36.11
E	〃	〃	82	136	10.0	84.78
F	〃	〃	163	〃	15.0	246.42

*小笹悦二・木元克則：ジンバルネットと通常型ネットの比較．1984年度日本海洋学会秋季大会で発表

$D(\mathrm{m}) = V \times T + 20$ ……………………………… (2)

ただし　V：曳網速度（m/sec.）

T：曳網時間（sec.）

20：ロープの長さ　(m)

結　　果

1.　濾水量

ネットの開口比と，曳網条件の相違に伴う濾水量の変化について Fig. 1 に示した．開口比と濾水量との関係については，一般に開口比が大きくなるのにともない濾水量も増大し，濾過すべき水柱量に近似すると考えられている[4]．ネット作製の際に設定した希望濾水量の85%の濾水量（以下85%濾水量と称する）に対して，Aネットの濾水量は曳網条件によって2.7〜7.2倍にも達しており，Bネットの濾水量は1.5ノットの速度で1分間曳網した場合のみ85%濾水量より少なく，これ以外の曳網条件による濾水量は85%濾水量の1.2〜4.1倍となっていた．Cネットの濾水量は1.5ノットの速度による6分間曳網と3.0ノットの速度による3分と6分間曳網の3条件が85%濾水量より多く1.2〜2.0倍であった．D，EおよびFネットはすべての曳網条件における濾水量が85%濾水量以内であった．

ネットがある距離を曳網された時に，実際に網目を

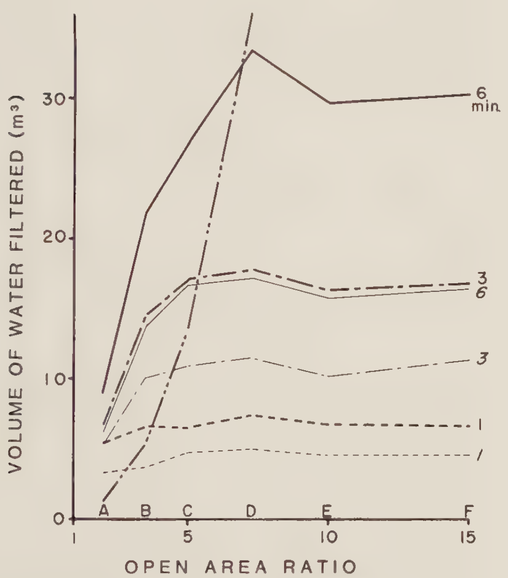


Fig. 1.　開口比の異なるネットの曳網時間と濾水量との関係

The relationship between the open area ratio and volume (m³) of water filtered at different velocity.

fine line : 1.5 knot

big line : 3.0 〃

broken line : 1 min.-tow

one point chain line : 3 〃

solid line : 6 〃

two point chain line : Acecepting 85% of the water presented to nets

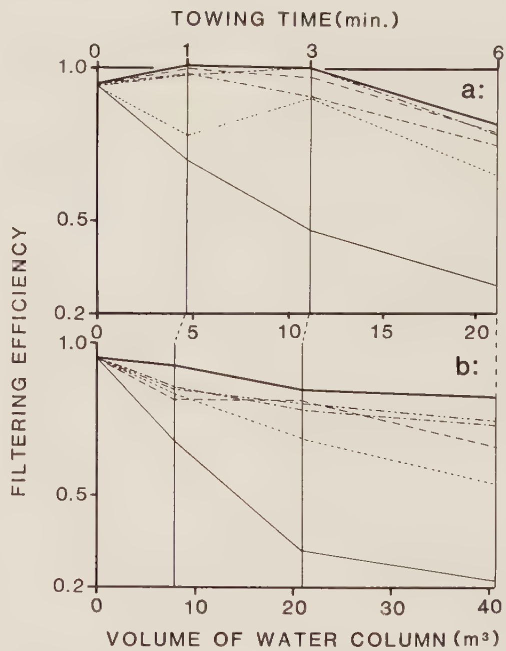


Fig. 2.　開口比の異なるネットの曳網時間と濾過効率との関係

Filtering efficiency of 6 type nets with different open area ratio.

a : 1.5 knot　　b : 3.0 knot

open area ratio

fine line : 2.0　　dotted line : 3.5

broken line : 5.0　　thick line : 7.2

one point chain line : 10.0

two point chain line : 15.0

通過した水量とネットの口輪が通過した水柱量との比である濾過効率（F'）は(3)式で求められる.

$F'=W/M\cdot D$ ……………………………………(3)

ただし　W：濾水量（㎥）　M：網口面積（㎡）

D：曳網距離（m）

ネットの開口比と，曳網条件に伴い濾過効率の変化を曳網速度別に Fig. 2 に示した. 前記6種類のネットを1.5ノットの速度で曳網した場合の濾過効率はDネットで大きく，6分間曳網でも0.8以上が得られたのに対し，開口比の小さいAネットのそれは0.3と最も小さかった. 曳網時間が長くなるのに伴い濾過効率は低下した. 曳網速度が2倍の3.0ノットの場合の濾水量はそれぞれ約2倍に達したが，濾過効率は1.5ノットの曳網速度の場合と同じように時間の経過とともに小さくなった.

2. プランクトン量

採集された動物プランクトンの1曳網当たり採集量(Fig. 3)は，開口比の小さいAネットで少なく，これより開口比の大きいB，Cネットで多かった. しかし，さらに開口比の大きなD，Eネットのそれは逆に減少してEネットは最も少なかった. 開口比の最も大きいFネットで採集された動物プランクトン量はD，Eネットのそれより多いがCネットのそれより少なかった. 曳網条件別の全ネットの採集量の平均値は，1.5ノットの速度で3分間曳網した場合は1分間曳網の4倍，さらに6分間曳網では8.3倍と曳網時間の延長に伴い増加した. また，3.0ノットの曳網速度で3分間曳網した場合のそれは1分間曳網の3倍，さらに6分間曳網では5.3倍に増加した. しかし，その増加率は1.5ノットの速度による曳網時より小さい. また，1分間曳網の1.5ノットの速度より3.0ノットの速度による採集量はわずかに増加しているものの3分と6分間曳網による増加はみられず，濾水量の増加に伴って採集量は増加しなかった.

単位濾水量（㎥）当り採集量（Fig. 4）は，すべて

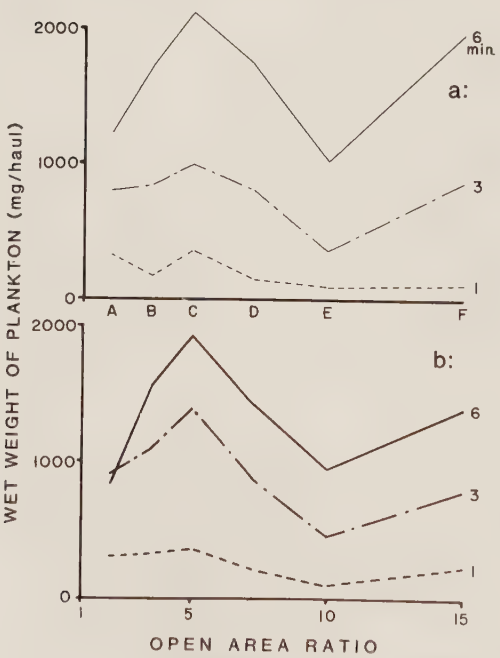


Fig. 3. ネット別，曳網時間別のプランクトン湿重量（mg/曳網）
Wet weight of samples collected at different conditions with open area ratio and towing time (mg/haul).
a : 1.5 knot　　b : 3.0 knot

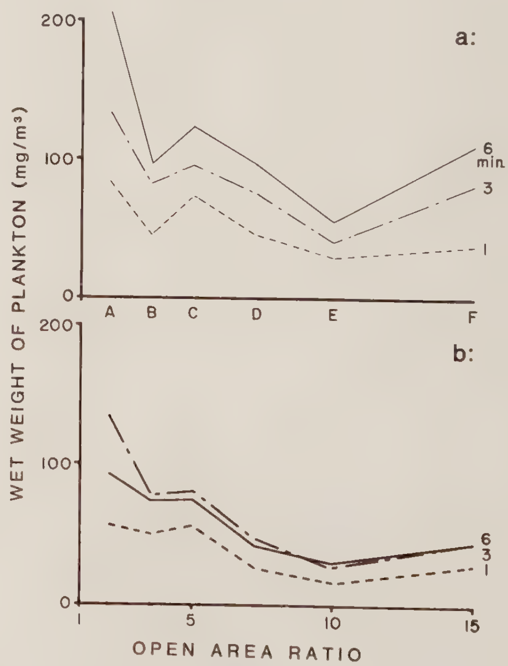


Fig. 4. ネット別，曳網時間別のプランクトン湿重量（mg/㎥）
Wet weight of samples collected at different conditions with open area ratio and towing time (mg/㎥).
a : 1.5 knot　　b : 3.0 knot

の曳網条件においてAネット（118mg/㎥）で多く，Eネット（33mg/㎥）で少なかった．1.5ノットの速度では曳網時間の延長にともない採集量は増加した．3.0ノットの曳網速度ではA，B，CおよびDネットでは3分間曳網より，6分間曳網による採集量が少なく，D，E，Fネットによる採集量に大きな変化はなかった．採集量を全ネットの平均値で比較すると，1.5ノットの速度で3分間曳網した場合には1分間曳網のそれより1.6倍，さらに6分間曳網では2.2倍に増加した．また，3.0ノットの速度による3分間曳網では1.8倍に増加したが，6分間曳網では3分間曳網より低い1.5倍にとどまった．

考　　察

ネットの網口から取り込まれた海水が網口から吐出されることなく，その全部が網目からゆるやかに抜け出るネットが生物に及ぼす影響は少なく，定性性および定量性が保証されよう．

各ネットの曳網中の状態は外観的には次のようであった．1.5ノットの速度で1分間曳網したAネットでは網地全体に付着物が観察されたが，開口比が大きくなるのに伴い付着物は少なくなった．Dネットでは網地の中央から網裾にかけて次第に付着物が多くなった．これに対しFネットの付着物はほとんど認められず，目詰りは起きていないように観察された．しかし，Fネットの濾水量はDネットより少なかった．このFネットが曳網中にネット全体が左右に大きくゆっくり振れていたことから推察すると，一般に曳網中のネットは網地の外側より内側の圧力が高いにもかかわらず，Fネットでは網口面積に対して網地面積が広すぎて網地の外圧の方が内圧より部分的に高まり外圧が網地にかかり，その部分の網地が内側に凹んで大きく振れて，濾過効率を低下させていたものと考えられる．

Tranter and Smith[5] は，口径57cm，網目幅330 μm のネットを沿岸域で1.5〜2.0ノットの速度で曳網した場合に濾水量49㎥までは濾過効率0.85以上を維持できたと報告した．今回使用したネットのうち，例えばBネットではその初期値（Table 1）から85%濾水量は5.35㎥であり，Fig. 1に示されたようにAネットの全曳網条件，Bネットの1.5ノットの速度の1曳網条件以外およびCネットの3曳網条件で85%濾水量を超えていた．Aネットは曳網速度に関係なく1分間以上の曳網では目詰りがひどく，3分と6分間曳網では濾過効率は0.5以下に低下した．各ネットの濾水量は，曳網時間が長くなるとともに増加したが，濾過効率は次第に小さくなった．このように濾水量が85%濾水量を超過するような曳網条件によって得られた濾過効率は最終的には著しく低下した．一方，Dネットの開口比はE，Fネットより小さいので，濾過効率はE，Fネットより小さくなるものと予想したが，逆にこれらより濾過効率は高かった．高い濾過効率を得るためにDネットの開口比と形状が使用条件に適合したものと考えられる．85%濾水量以下の濾水量を得るような同一曳網時間では開口比の相違による濾水量の変化は少なかった．

1曳網当りの全ネットの平均採集量は，1.5ノットの曳網速度では曳網時間の延長にともない増加したが，3.0ノットの曳網速度ではその増加率は1.5ノットの曳網速度のそれより小さかった．これは，曳網速度が遅いと曳網開始の早い時期に目詰りが起こり網地に付着した大型プランクトンの上にさらに小型のプランクトンが重なって採集されるのに対して，曳網速度が速いと群体を形成している植物プランクトンの分離や動物プランクトンの付属肢等が損傷して網目から抜けだし，目詰りするプランクトンが少なかったことによると推察される[10]．1曳網当り採集量は曳網時間が長くなるとCネットを最大として，D，Eネットでの減少が大きくなっている．曳網条件が同一になるように設定して採集を行ったことからすると，Eネットが特にプランクトンの少ない層を曳網したとは考えられないので，Eネットの採集量が特に少なかった原因は不明である．

単位濾水量当り採集量は濾水量の少ないAネットで多かった．使用したネットはⅠ（A〜Dネット）とⅡ（D〜Fネット）の組合せで曳網されたので，各組合せ内における各ネットの曳網条件は同じと考えられる．それにもかかわらず，Bネットの採集量はA，Cネットのそれより少なく，特に1.5ノットの曳網速度においてこの傾向は顕著に現われた．しかし，このA，

BおよびCネットでは85%濾水量を超過した濾過水量であるため論議はさしひかえたい．採集量は曳網条件に関係なく，得られた値は同じになるべきものと考えられるが，今回の実験結果（Fig. 4）では1.5ノットの曳網速度によるそれは，曳網時間の延長に伴って単位濾水量当り採集量も増加している．これは曳網時間の延長に伴ってネットの目詰りが多くなり濾水量が少なかったことによるためと考えられる．3.0ノットの曳網速度のそれは1分間曳網より3分と6分間曳網速度では増加しているが，3分間曳網と6分間曳網では同じ採集量になっている．これは1.5ノットの2倍の速度で曳網されたので1.5ノット曳網時より目詰りが少なかったことによると考えられる．

開口比が大きいネットの場合には目詰りが少ないので小さな生物は捕集されず単位濾水量当り採集量が少なくなるのであろう．しかし，これが所定の網地で採集される水域のプランクトン組成と現存量を現していると言えよう．一方，同一場所で曳網速度を変えて連続して行った採集実験[10]では2.5ノットの曳網速度で植物プランクトンによる目詰りが起きた．しかし，5.5ノットの速度では植物プランクトンは採集されなかった．このように同一水塊内であっても曳網速度によって採集された生物組成が異なることがある．

還流水槽を用いてAネットとCネットの流況を調べた結果[9]では，Aネットは網口前方の流速よりネット内部の流速が遅かった．一方，Cネットは逆に網口前方よりネット内部の流速が速かった．これはAネットではネット内の水圧を狭い網地開孔面積で受け止めたために流速が低下したのに対し，Cネットは開口比が大きく網地開孔面積が広いため網口から流入した水は網地抵抗が少なく，逆にネットの吸引現象が起きてネット内部の水流が網口前方の水流より速くなっていたと推察される．濾過効率が開口比 $R=5\sim7$ の範囲で大きいことは本実験でも明らかにされた．一方，ネット内における生物の損傷はAネットで小さく，D，Fネットで大きい結果が得られている[10]．この理由として今回の実験により以下のことが推定される．すなわちAネットは曳網開始後早い時期にまず大型のプランクトンによる網地の目詰りが起こり，さらにその上に小型のプランクトンが重なって目詰りがひどくなり濾過効率の低下により濾水量は減少し，ネット内の水流が遅くなりその後に取り込まれる生物は損傷が少なくなる．これに対し濾過効率の高いネットでは網地面積が広く，ネット円筒部の波動による自浄作用とネットの吸引効果の相乗作用により，目詰りが少ないために濾水量が多く，ネット内の水流も速いので生物が網地にはげしく衝突して損傷が大きくなると考えられる．

これらの結果から採集水域のプランクトン現存量を把握するには，希望濾水量にもとづいて濾過効率の高いネットを作製し，85%濾水量を超過しないように，また曳網速度を充分考慮して採集を行うことが肝要である．

要 約

沿岸水域において，網口面積と網地を統一した開口比の異なる6種類のネットで採集実験を行った．ネットの開口比の相違が濾水量と生物の採集量に及ぼす影響を検討するために，曳網速度と曳網時間を組み合わせて動物プランクトン210標本を採集した．

開口比が $R=7.2$ のネットが最も濾過効率は高く，これより大きくても小さくても濾過効率は低下した．

濾水量は曳網時間が長くなるとともに増加したが，同じ開口比のネットによる1曳網当り採集量は曳網速度が速くなっても増加しなかった．開口比が小さく濾過効率が小さいネットほど単位濾水量当りの採集量が多くなり，現場の生物量を反映しない結果になった．この現象は開口比の小さいネットがより多く目詰りを起し，より小さい生物を捕集した結果になったものと推測される．このため，プランクトンを採集する場合には，濾過予定水量と対象となるプランクトンの種類によってネットの口径，網地さらに開口比を決め，85%濾水量を超えないように採集することが肝要であると結論づけられた．

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Small-scale Spatial Distribution of Fish Larvae, Mesoplankton and Plant Pigment in an Area to the West of Kyushu in Spring

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To resolve a discrepancy that even mean standing stock of zooplankton is far in excess of the food requirement of fish larva, and the fact that many fish larvae are famished, a unit of 0.2 miles towing of the larva net, 100 μm mesh net plankton collection and chlorophyll *a* observations were made in an area of 1.2 miles × 1.0 mile in the northernmost area of the East China Sea, May 1985, March–May 1986. The area was selected because of the relative uniformity of watermass. Spatial distribution of many elements showed contagious distribution with a center diameter less than one or two units of tow. A trial estimation showed that food requirement of fish larva is 0.15–1.5% of zooplankton production, and food demand of zooplankters is 2.7–34.8% of primary production in mean. It is concluded that the spatial distributions of fish larvae, net plankton, and chlorophyll *a* have no quantitative relationship with each other, and is also not governed by the property of sea water in terms of salinity.

INTRODUCTION

High scarcity of contents in the stomachs of pelagic larvae was observed in flounder, *Paralichthys olivaceus*, in the Goto-nada waters to the west of Kyushu, the northernmost area of the East China Sea during May 1982–1985.[1] The same authors induced that the larvae with vacant stomachs are actually famished, by comparing the previous data on food requirement with value of those on stomach full and turn over rate of food in the stomach for the flounder larvae. On the other hand, they reported that the distribution density of prey organisms for the larvae is far enough to fulfill their food requirement. Patchy distribution of prey organisms may resolve the discrepancy between the two phenomena: many larvae fail in catching the prey and some succeed. Plankton animals show certain non-random, patchy distribution in some spatial scales, i. e., less than 1 m, from 1 to 100 m, and more than 100 m.[2] Many eye-observations on board[3,4] and detailed submergible sampling operations[5–7]

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documented the presence of the patchiness.

In the present paper particular interest is focussed on comparing the spatial distribution pattern in fish larvae, net plankton and phytoplankton pigment, and some quantitative relationships between them are considered basing on the estimations of the food requirement of the predator and productivity of prey organisms.

MATERIAL AND METHOD

Continuous surface layer horizontal tows with the larva net (130 cm in mouth dia., 450 cm in side length, 500 μm mesh aperture) were carried out alternately from port and starboard of the research ship "*Yōkō Maru*" of the Laboratory on 6 lines of 1.2 miles set at an interval of 0.2 miles in the central part of the Goto-nada waters, May 1985, March-May 1986 (Fig. 1). The grid of rectangle was set not on the geographical position but on the plane of watermass with a correction de-

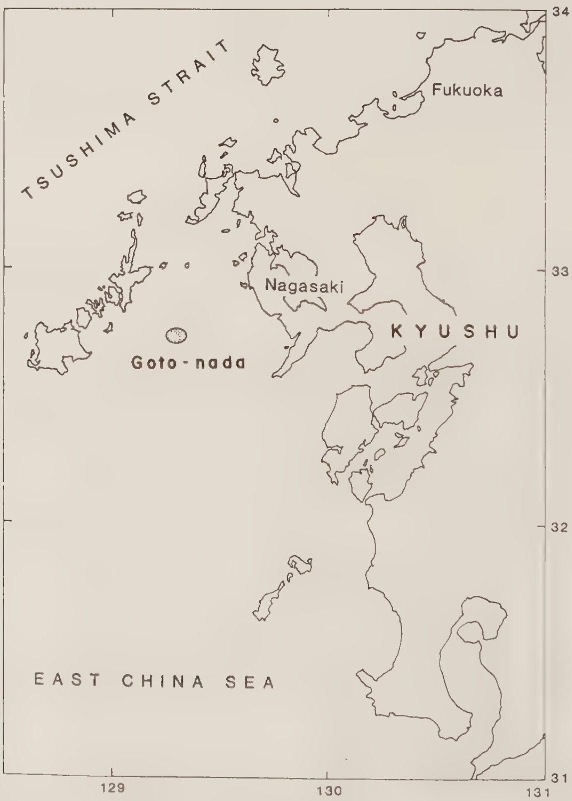


Fig. 1. Location of gird survey area for small-scale spatial distribution of plankton in the Goto-nada waters, May 1985, March-May 1986.

pending on the direction and speed of the water current measurement. The area was decided according to its uniformity of oceanographical properties of the water mass (Table 1), and relatively slow currents.*

Table 1. Temperature and salinity duiring the grid survey of fish larva net tow and plankton samplings in the Goto-nada waters, to the west of Kyushu, May 1985, March-May 1986

Date	Hour	Temperature(°C)	Salinity
May 14-15, 1985	1959-0103	19.4-19.5	
March 15, 1986	1121-1438	14.3-14.3	34.63-34.66
April 12, 1986	1200-1657	16.1*	34.69-34.72
May 15, 1986	0810-1316	18.4-18.5	34.21-34.31

* At Stn., 32°47′N, 129°16′E, April 13, 1986 (NAGASAKI PREF. INST. FISH., unpublished)

The distance of tow, 0.2 miles, was decided to fulfill the minimum level for the quantitative study of fish larva distribution with the fish larva net. Hour given in Table 1 is the interval of fish larva net towing. Temperature was measured at the bottom of the ship at 5 minute intervals. It varied horizontally so little its distribution was left out of consideration in later discussions.

Sea water was drawn with a pump system through the duct which opened at the bottom of the ship (depth of 5 m) on the midway of the fish larva net tow. Net plankton was collected by sieving with 100 μm meshed small plankton net. Crude sea water was processed for fluorometric chlorophyll *a* determination and salinity conductivity measurement. Volume of water sampled for study of each element is shown in Table 2.

Table 2. Volume of water sampled for quantitative study of fish larva and other plankton in the Goto-nada waters, May 1985, March-May 1986

	Fish larva (m^3)	500μm plankton (m^3)	100μm plankton (ℓ)	Chlorophyll *a* (mℓ)
May 1985	451±46	451±46	375	300
March 1986	417±56	417±56	332	300
April 1986	414±53	414±53	335	300
May 1986	441±26	441±26	337	300

± number : Standard deviation

Fish larvae were sorted from the fish larva net samples and divided into 2 groups by expedient category, i. e., "Shirasu" form of clupeid larva and the others. The specimens with body longer than 15 mm in Shirasu and 10 mm in the

* K. TSUKIYAMA, personal communication

other fish were excluded. The number of individuals was counted and wet weight for the batch of a sample was measured at 0.01 mg. Wet weight of specimen other than fish larva in the larva net samples and 100 μm net plankton sample was also determined. The position of the plot on the figures for the horizontal distribution of organisms is the middle point on the segment of the fish larva net tow.

ESTIMATION OF FOOD REQUIREMENT AND PRODUCTION

1. Food Requirement of Fish Larvae

Shirasu : For food requirement estimation on Shirasu form, data on Californian anchovy, *Engraulis mordax* are used here. Food requirement (F) is given from the knowledge of rates of growth (net production, Pn), metabolism loss (respiration, R) and assimilation efficiency of food (A) as follows[8] :

$$F = (Pn + R) / A \quad \cdots\cdots \quad (1)$$

Respiration rate for the anchovy is given as $R=4.5\,\mu l$ O_2/mg dry weight/hr by HUNTER.[9] This formula is rewritten on basis of dry weight as follows when 1 μl O_2 is equivalent to 0.00477 cal[8] and 1 cal is 0.2 mg dry weight of body tissue[10] :

$$R \text{ (mg dry wt./mg body dry wt./day)} = 0.103 \quad \cdots\cdots \quad (2)$$

KRAMER and ZWEIFEL[11] described a growth trend of *E. mordax* in terms of body length (L, mm) at t-th day after hatching:

$$L = 3.24\ e^{0.0555t} \quad \cdots\cdots \quad (3)$$

The length(mm)-body weight (wet ?, mg) relationship in *E. mordax* is given by LASKER et al.[12] as

$$\log W = 3.3237 \log L - 3.8205 \quad \cdots\cdots \quad (4)$$

Substituting Eq. 3 into Eq. 4.

$$W = 7.523 \times 10^{-3} \times e^{0.1845t} \quad \cdots\cdots \quad (5)$$

This means that daily weight specific growth is 0.1845. When the assimilation efficiency of food is 0.8,[8,13] daily body weight specific food requirement of Shirasu is given as follows:

$$F = (0.103 + 0.1845) / 0.8 = 0.359 \quad \cdots\cdots \quad (6)$$

Miscellaneous fish larvae : The respiration rate (μl O_2/animal/hr) of flounder, *Paralichthys olivaceus* of weight of W (mg dry weight/animal) at the temperature of T°C

is given by MORIOKA[13] : $R=1.09\times2^{T/10}\times W^{0.795}$. When the mean ambient temperature in the sea is 17℃, the respiration (mg dry wt./animal/day) is expressed as :

$$R = 0.0811W^{0.795} \quad \cdots\cdots (7)$$

We get daily weight specific respiration from Eq. 7 as :

$$R / W = 0.0811W^{-0.205} \quad \cdots\cdots (8)$$

The growth rate (Pn) of the flounder at temperature of T℃ at t-th day after hatching is given by MORIOKA [13]:

$$Pn = 0.514 \times 2^{T/10} \times e^{0.0657t} \quad \cdots\cdots (9)$$

Eq. 9 means that the daily weight specific growth rate is 0.0657. The weight specific daily food requirement (mg dry weight) is derived from substituting these into Eq. 1 under the same assupmtion as in the Shirasu as follows :

$$F = (0.0657 + 0.0811W^{-0.205}) / 0.8$$
$$= 0.0821 + 0.101W^{-0.205} \quad \cdots\cdots (10)$$

Food requirements of Shirasu and the others are obtained from the mean wet body weight of larva (Table 3) and Eqs. 6 and 10. Dry basis is available to convert from wet one by multiplying 0.2 as an approximate value for Japanese anchovy and Evermann's lantern fish larvae.[14]

Table 3. Mean weight (Wet, mg/animal) of 2 categories of fish larvae in a tow in the Goto-nada waters, May 1985, March-May 1986

	Shirasu			Miscellaneous		
	Number	Mean	SD	Number	Mean	SD
May 1985	36	5.526	2.525	36	2.775	2.021
March 1986	24	0.528	0.267	17	0.631	0.536
April 1986	36	0.281	0.259	34	1.869	1.173
May 1986	16	0.742	0.230	36	1.097	0.423

SD : Standard deviation

2. Production of Prey Animals

100 μm net plankton : Material collected with 100 μm mesh net may not be always the food of fish larvae, because it sometimes contains certain amount of phytoplankton cells and non-living substance, etc. But the majority is zooplankters with body length of less than 1 mm (Fig. 2), which consisted of nauplii and copepodite stages of copepod genera such as *Paracalanus*, *Clausocalanus*, *Acartia* and *Oithona*. These appear in the stomachs of flounder[1,15,16] and anchovy larvae.[17,18] Ratio of produc-

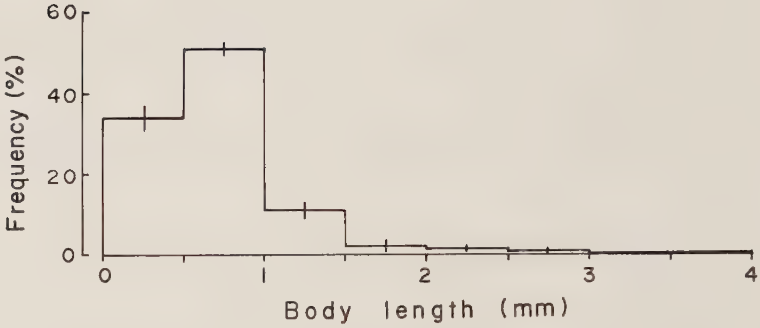


Fig. 2. Body size distribution of zooplanktonin 11 samples obtained with 100 μm mesh net in the Goto-nada waters (pump system, May 1985 grid survey). Vertical bar shows 95% confidence limit.

tion to biomass, P/B ratio, of copepod *Acartia omorii* as a representative species which has similar body size to the above copepods[19] is 0.1 per day* in Shijiki Bay with the oceanographic conditions like that of the present area.

500 μm net plankton: *Calanus sinicus* was tentatively elected as the representative of the organisms collected with the larva net of 500 μm mesh aperture because it was abundant in May for two years. Zooplankters were meager in the earlier months (abundant diatoms in March and scarce fish eggs and so on in April). An individual of *Calanus* weigh 110 μg in dry weight,[19] and its daily productivity to the biomass shows 0.06 at the temperature of 17℃ reading the body weight-P/B ratio diagram by MORIOKA.[20]

3. Food Requirement of Zooplankton

IKEDA and MOTODA[21] chose a value of 0.3 for K_1, the gross growth efficiency, ratio of production (Pn) to the food requirement (F), compiling the results of laboratory experiments by the previous workers. Therefore, F is given as:

$$F = 3.33\,Pn \quad \cdots\cdots \quad (11)$$

Since one miligram wet weight of animal tissue is equivalent to 0.2 mg dry weight in general zooplankton[14] and carbon/dry weight ratio is 0.4 (from the text figure of IKEDA[22]), daily weight specific food requirement on carbon basis is given as: for 100 μm net plankton,

$$F \text{ (mg C/day)} = 0.0267 \times \text{Biomass (mg, wet wt.)} \quad \cdots \quad (12)$$

and for 500 μm net plankton.

* K. KIMOTO, unpublished

$$F\,(\text{mg C/day}) = 0.0160 \times \text{Biomass (mg, wet wt.)} \quad \cdots \quad (13)$$

4. Phytoplankton Production

Primary production measured by ^{13}C method at 2 stations located ca. 30 miles north of the present area amounted to 0.15-2.2 gC/m²/day during 12 months.[23] The monthly mean assimilation number (mgC/mg Chl. *a*/day) obtained from the above values and standing crop of chlorophyll *a* at the two stations was 31.2 (range: 10-60, standard deviation: 14.9) excluding an extraordinary high value. A daily assimilation number of 30 was here adopted to calculated the primary production from the standing crop of chlorophyll *a* in the present area.

RESULTS AND DISCUSSION

The number of fish larvae varied according to month. Clupeid larva, Shirasu, ranged from 2 to 130 individuals per 1,000 m³ of water in monthly mean and the larvae other than Shirasu 5 to 200. Biomass in wet weight accordingly varied too: that of Shirasu amounted to 2-500 mg per 1,000 m³ of water and miscellaneous fishes 3-480 mg. The highest values in both larvae were observed in May 1985, in which the towing were made at night (Table 4). Fig. 3-a gives their horizontal distribution by month. They performed no uniform pattern, and the amount of each varied even in the narrow area. One or two patchiness of distribution was observed in the area showing a contagious distribution with a center of scale with a diameter of 0.2 miles. Its biomass was 2-9 times the mean amount in the whole area. Each

Table 4. The number and biomass of 2 categories of fish larva in the Goto-nada waters, May 1985, March-May 1986 (number in parentheses is range)

	Number per 1000m³						Biomass wet wt. μg per m³					
	Shirasu			Miscellaneous			Shirasu			Miscellaneous		
	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD
May 1985	35	97.8	48.9	35	203.3	71.3	36	496.9	290.6	36	480.2	201.8
		(24.1-273.8)			(69.4-404.7)			(72.3-1554.5)			(131.3-891.8)	
March 1986	24	88.2	143.5	24	4.8	7.1	24	48.8	90.0	24	3.1	4.8
		(2.4-693.6)			(0 - 28.6)			(0.2-450.2)			(0 - 19.4)	
April 1986	36	132.7	141.6	36	13.8	10.3	36	30.7	33.3	36	23.6	23.4
		(2.6-588.1)			(0 - 37.0)			(0.2-167.4)			(0 -131.0)	
May 1986	36	1.9	3.4	36	49.1	16.9	36	1.7	2.7	36	51.4	22.1
		(0 - 17.2)			(19.1- 81.7)			(0 - 13.4)			(10.8- 97.6)	

No.: The number of samples
SD: Standard deviation

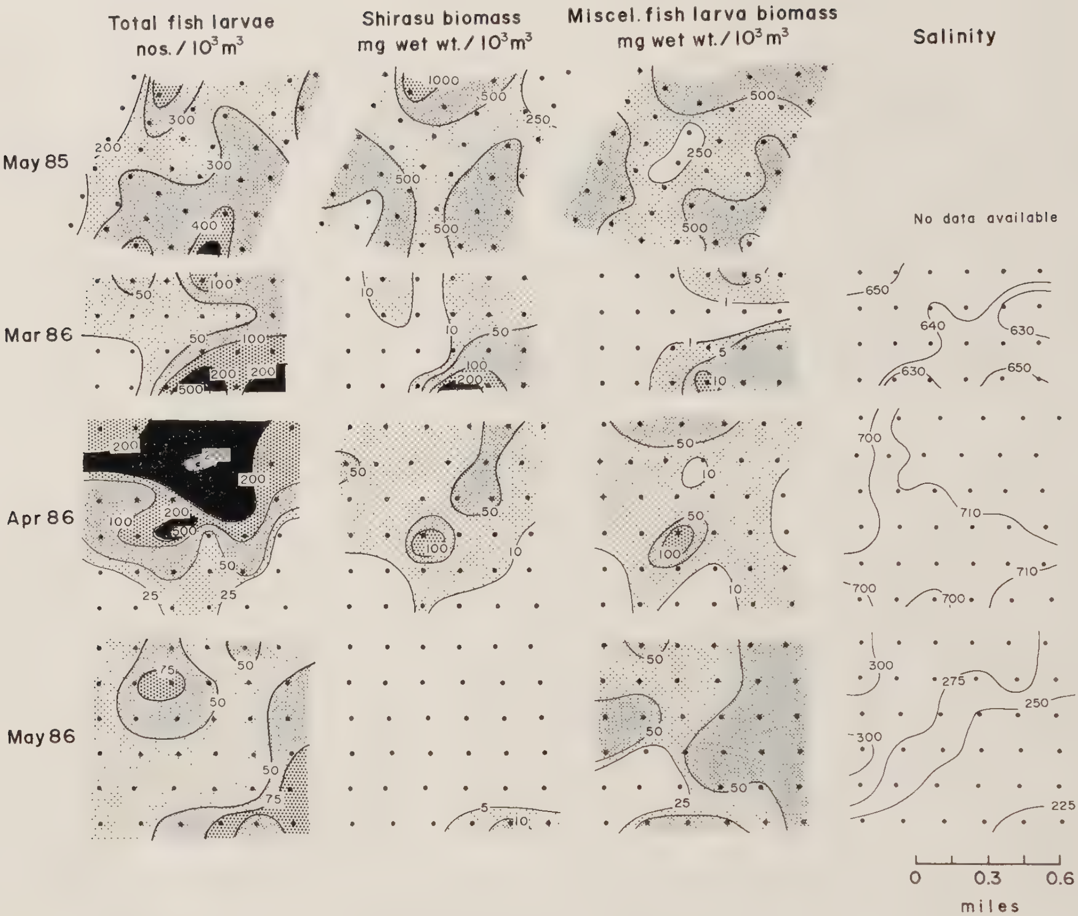


Fig. 3-a. Horizontal distribution of fish larvae and salinity ((-33)×1000) in grid survey in the Goto-nada waters, May 1985, March-May 1986.

pattern does not correspond to that of water mass in terms of salinity (Fig. 3-a).

Biomass of plankton caught with 500 μm mesh fish larva net ranged 1-100 mg wet weight per m^3 of water in mean, and that with 100 μm mesh ranged 50-200 mg. They also showd maximum value in nocturnal sampling in May 1985 (Table 5). A contagious horizontal distribution was also observed in the area surveyed, and scale of diameter of the high density population does not exceed 0.2 miles. The pattern does not correspond only to fish larva distributions but also to salinity distribution in the same manner as in the fish larva distribution (Fig. 3-b). Chlorophyll *a* content amounted to 0.3-2 mg per m^3 in monthly mean, showing a maximum in April 1986 (Table 5). The horizontal distribution pattern does is not coincide with the areal figures of zooplankton and salinity (Fig. 3-b).

To sum up, all elements observed have their own distribution pattern regard-

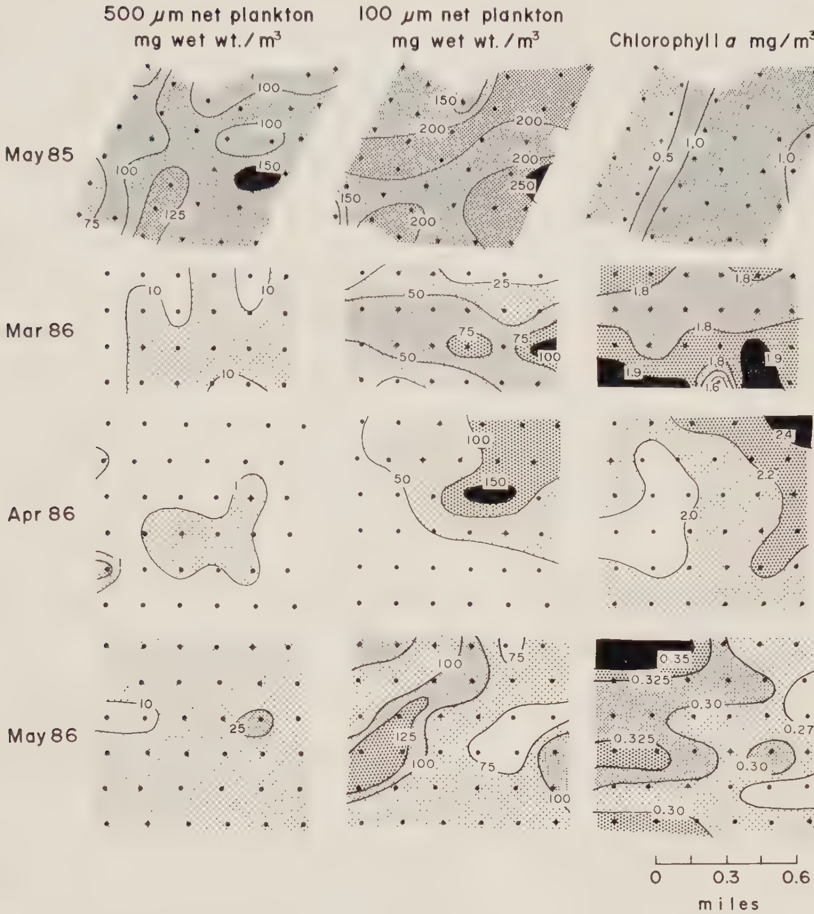


Fig. 3-b. Horizontal distribution of net plankton and phytoplankton pigment in grid survey in the Goto-nada waters, May 1985, March-May 1986.

less the interrelationship among them and may not be governed by salinity gradient. The spatial scale of patchiness of each element never exceed 0.2 or 0.4 miles in diameter of a units of tow. Exact scale may sometimes be smaller than these.

As it is considered generally that fish larvae, zooplankton, and phytoplankton are linked together by food relationship, quantitative considerations must also be discussed. Table 6 gives food requirement of predator and productivety of its food. The sum of daily food requirement of Shirasu and other fish larvae is 0.15-1.5% of daily productivity of 100 μm mesh net plankton. Similarly, plankters caught with 500 μm and 100 μm mesh net require 2.7-34.8% of primary production. Even in the segment of maximum food requirement of fish larvae and zooplankton it does not exceed 5% of prey animal production and 70% of primary production, respectively. It is concluded from these that areal abundance of fish larvae, zooplankton and

Table 5. Net plankton biomass (wet wt., mg/m³) and amount of chlorophyll *a* (mg/m³) in the Goto-nada waters, May 1985, March-May 1986 (number in parentheses is range)

	500 μm net plankton			100 μm net plankton			Chlorophyll *a*		
	No.	Mean	SD	No.	Mean	SD	No.	Mean	SD
May 1985	34	102.5 (58.0-141.4)	19.8	35	198.8 (56.1-259.2)	35.7	36	0.87 (0.33-1.22)	0.37
March 1986	24	10.9 (2.1- 17.1)	3.8	24	48.2 (14.7-112.1)	22.8	24	1.82 (1.54-1.98)	0.10
April 1986	36	0.8 (0.4- 2.9)	0.4	36	66.2 (23.9-167.2)	38.8	36	2.12 (1.91-2.60)	0.16
May 1986	35	16.2 (6.1- 30.3)	5.8	36	90.5 (47.5-151.3)	28.2	36	0.30 (0.22-0.36)	0.03

No. : The number of samples
SD : Standard deviation

Table 6. Percentages of food requirement of total fish larvae (Fl) to 100 μm net plankton production (P_{100}), and food requirement of 500 μm and 100 μm net plankton ($F_{500 \cdot 100}$) to primary production (P_p)

	$Fl/P_{100} \times 100$			$F_{500 \cdot 100}/P_p \times 100$		
	Mean	SD	Range	Mean	SD	Range
May 1985	1.49	0.84	0.64-4.61	34.8	19.5	14.4-69.0
March 1986	0.92	0.96	0.00-4.69	2.7	1.1	0.8- 5.6
April 1986	0.27	0.30	0.00-1.68	2.8	1.6	1.0- 7.2
May 1986	0.15	0.08	0.04-0.39	30.2	8.3	16.4-47.0

SD : Standard deviation

phytoplankton are entirely independent. Rather, manner of spawning eggs in organisms, weak movement of watermass and anything else including social behavior of organisms are interesting for the factors governing the spatial distribution of planktonic organisms.

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春季の五島灘における魚類稚仔，動物プランクトンおよびクロロフィル量の微細分布

森岡泰啓・中嶋純子・木元克則

抄　録

海洋現場で採集された魚類稚仔の食物要求量が餌料プランクトン生産量のほんのわずかな部分にしかあたらないにもかかわらず，多くの稚仔の消化管が空であることから，稚仔や餌料プランクトンが均一ではなくパッチ状の分布をしているとの想定のもとに，それらの水平分布の対応状態を調査した．

1985年5月，1986年3，4，5月の4回（1985年は夜間，1986年はいずれも昼間），五島灘の中央部海域において調査船陽光丸（499トン）によって稚魚ネットの表層曳と船底（水深5 m）に開口する管を通じてのポンプ揚水を行なった．海域は物理・化学的になるべく均質なところとして選ばれた．0.2マイル間隔に相並ぶ1.2マイル長の6線上で網目0.5㎜の稚魚ネットによる船速2ノット，6分間ずつの左右両舷交互の連続採集を反復し（1網約0.2マイル，1線上で6回），都合36対の標本を得た．6本の航路は地理上にではなく，潮の流向，流速を実測のうえ水塊上にできるだけ方形になるよう配置された．

測定項目は，稚魚ネット採集物からはイワシ類等のシラスとその他の魚類稚仔の個体数密度と生物量，それに魚類以外の動物プランクトン生物量，ポンプ採水試料からは0.1㎜のネットでこし取ったプランクトンの生物量とクロロフィルa量とである．

間隔5分間で測定された表面水温は各月とも調査海域内でほぼ一様といってよく，最大の幅は0.1℃であった．

稚仔，ネットプランクトン，クロロフィルともに1網（0.2マイル長）または2網を1単位とする濃密な

パッチを中心とした伝幡的な分布を呈した．パッチは海域内に概ね1個存在した．ただ，おのおのの要素の分布の“模様”はそれぞれ異っていて，そのいずれにも塩分の分布型との一致がなかった．稚魚，ネットプランクトン，そして植物プランクトンが食物環によって直接につながっているとして，それぞれの食物要求量と生産量を既往資料を用いて試算すると，稚仔の食物要求量は0.1㎜ネットプランクトンの0.15〜1.5%，0.5㎜と0.1㎜ネット分画のプランクトンの食物要求量は基礎生産量の3〜35%にあたることになった．すなわち，プランクトン各要素の分布量はわずかな塩分の傾斜に左右されることなく，食物段階において一段階下位にある生きものの分布量に影響を及ぼす程の摂食圧を捕食者は有しない．さらに小さな空間的尺度での検討を要する．

Segregation of Vertical Distribution of Calanoid Copepod *Acartia omorii* Depending on the Developmental Stages in Shijiki Bay, Western Kyushu, Japan

Katsunori KIMOTO*

Samples of vertical segregation of *Acartia omorii* (Copepoda: Calanoida) according to the developmental stage were obtained during daytime by a submersible pump collection system at two stations (10.8 and 6.3 m in depth) in Shijiki Bay, a small inlet of Hirado Island, western Kyushu, Japan, on March 11, 1982. All the six stages of nauplius of *Acartia* occurred throughout the water column from the surface to the mid layers at the two sites. Copepodites older than stage Ⅲ, on the other hand, appeared in the layer with heights of 0.5 m just above the sandy bottom and of 1 m above the bottom throughout the eelgrass bed. The vertical distribution of *Acartia* changed drastically by metamorphosing from nauplius into copepodite, while copepodite stage Ⅰ and Ⅱ are likely in a transitional period during their ontogenetic specific distribution. These distributions seemed to persist through the activities peculiar to the developmental stages of copepod.

INTRODUCTION

In the coastal and neritic temperate waters of Japan, some planktonic copepods showing remarkable vertical distributions by developmental stages have been investigated; *Acartia clausi*, *Calanus sinicus* and *Paracalanus parvus* in Ise Bay,[1] *Acartia* spp. (*A. hudsonica* and *A. omorii*) and *Paracalanus crassirostris* in Maizuru Bay.[2] These copepods show a specific distribution pattern during the daytime.

In Shijiki Bay, a small inlet southwest of Hirado Island, western Kyushu, advanced stages of copepods of *Acartia omorii* and *A. steueri* are distributed near the bottom and are fed upon by demersal juvenile of red sea bream.[3-5] But little is known on the distribution of naupliar and early copepodite stages of *Acartia*. Clarification of vertical distribution of copepods according to developmental stages is necessary to learn the population dynamics of copepods, their productivity and their availability as food for fish.

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Here are shown a few samples of segregated vertical distributions of *A. omorii* according to developmental stages taken from a minute sampling in the inner part of the Bay, using a pump collection system.

MATERIALS AND METHODS

Sampling was made at two stations in Shijiki Bay, in the afternoon (Stn. 1 ; 14 : 05–14 : 25, Stn. 2 ; 13 : 40–13 : 52) of March 11, 1982. Bottom materials of Stn. 1 (33°11.41′N, 129°23.94′E) was sand, and that of Stn. 2 (33°11.54′N, 129°24.24′E) was eelgrass (*Zostera marina*) bed. The depth of sea bottom showed 10.8 and 6.3 m at Stns. 1 and 2, respectively. Copepods were filtered with nylon gauze (50 μm mesh opening; type, nytal® DIN 110–50) from a volume of 20 *l* of seawater which was drawn by a submersible electric forcing pump (Tsurumi Seisakusho Co., Model SQ2-3Y, 1.8 *l*/sec) at 22 layers for Stn. 1 and 13 for Stn. 2 at 0.5 m intervals from surface to bottom. Samples were preserved in seawater formalin solution. Water temperature, salinity and fluorometrical concentration of chlorophyll *a* and phaeopigments of sea water were measured at 3 to 5 layers from surface to bottom at each station.

Individuals of *Acartia* were counted by developmental stage and sex. In Shijiki Bay, *Acartia steueri* and *A. omorii* occur together.[6] The author was not able to distinguish *A. steueri* from *A. omorii* by the presence or absence of the rostral filaments in the copepodite I and naupliar stages.[3,7,8] But the occurrence of *A. steueri* might be negligible, as its advanced stages were very scarce at these sampling sites, particularly at Stn. 1. The counting was made for the whole body of the sample in general. When copepods were too many, counting was done sometimes on an aliquot of 1/2, 1/4, 1/8.

RESULTS AND DISCUSSION

The day being fine and calm. Transparency was 10 m at Stn. 1 and more than 6.3 m at Stn. 2. Temperature of seawater of the whole water column at the two stations showed 13.4°–14.0℃. Concentration of chlorophyll *a* ranged from 2.3 to 4.2 μg/*l*. There was no distinct vertical inclination in these two stations.

The vertical distribution of the individuals of *Acartia omorii* at two stations is shown in Fig. 1.

Stn. 1: The nauplii (N II to N VI) of *Acartia* was distributed throughout the water column from surface to bottom showing a small peak at the layers between 4 and 5 m deep. However, copepodites distributed at the layers deeper than 4 m. Furthermore, copepodites older than stage III concentrated just above the sandy bottom.

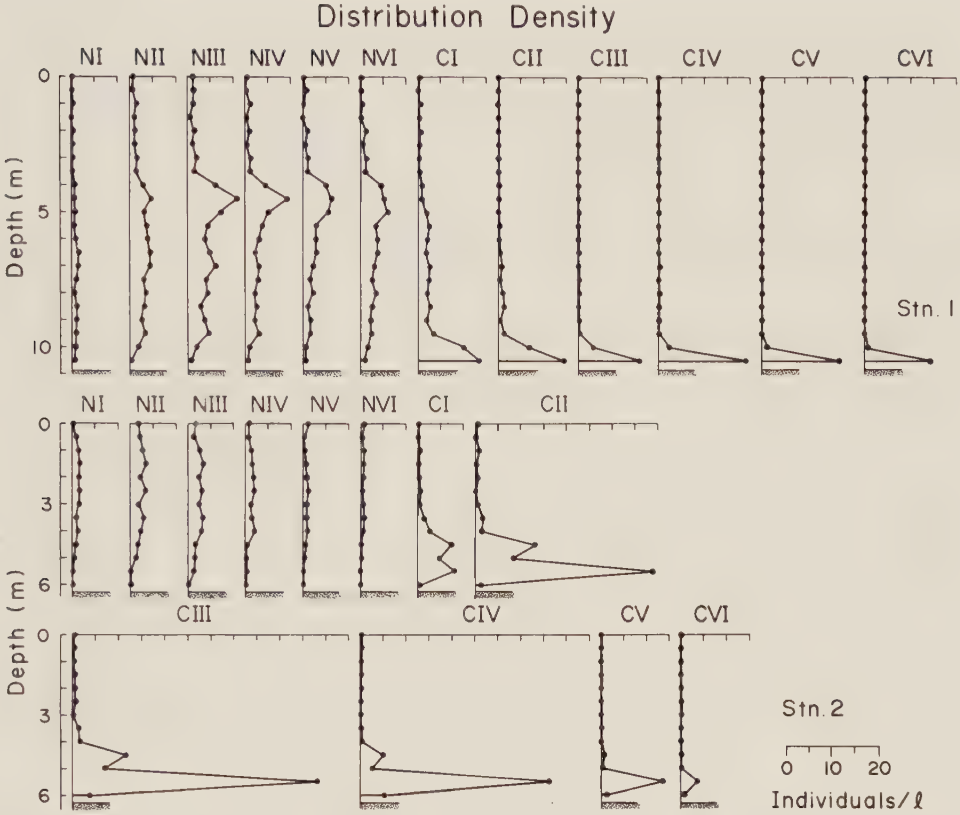


Fig. 1. Vertical distribution of *Acartia omorii* in each delopmental stage (N-:nauplius, C-:copepodite) collected with an assembly of pump system in Shijiki Bay, March 11, 1982.

Thickness of the layer of the distribution was smaller than 0.5 m. Eighty-seven percent of adult *A. omorii* and forty-nine persent copepodites adults excluded, concentrated at the layer of only 0.5 m thick at a depth between 10 and 10.5 m.

Stn. 2: The nauplii of *Acartia* distributed at layers between 0 and 5 m deep. But the copepodites distributed at layers between 4.5 and 5.5 m in depth. The copepodites must be distributed within and just above the eelgrass bed, because eelgrass blades are ordinarily as tall as about 0.5 to 1 m. Ninety-four persent of adult *A. omorii* and seventy-one persent of copepodites concentrated at a layer one meter thick between 5 and 6 m deep.

These two samplings show that copepodites and adult *A. omorii* distributed just above the bottom, while the nauplii distributed between the surface and the middle layers. These results were similar to those obtained by UEDA,[2] *i.e.*, that copepodites of *Acartia* spp. descended with age and the adult stage mainly occupied the bottom from March through May in Maizuru Bay. At the same time, he observed that in

March copepods also distributed in the surface layer. In Shijiki Bay, the organism changed the vertical distribution drastically by metamorphosing from nauplius into copepodite. Copepodite stages I and II are likely in a transitional period. The segregation of habitat between nauplius and copepodite may be caused by some difference of perception to light intensity between the two stages.

ANRAKU[9] investigated micro-scale distribution of copepod using a pump collection system in Oshoro Bay, west coast of Hokkaido. He observed that copepods of *Acartia clausi* displayed epibenthic characteristics in its distribution in daytime, even at twilight, then got off the sea bottom and dispersed themselves about the water column at night. UEDA *et al.*[3] and TANAKA *et al.*[4] observed by SCUBA diving that copepodites of *A. omorii* and *A. steueri* formed flat or irregular ball-shaped swarms near the flat sandy bottom and that *A. steueri* distributed throughout eelgrass beds in Shijiki Bay in daytime. The author also observed the swarms of *A. omorii* and *A. steueri* by SCUBA diving just above the sea bottom of Shijiki Bay in the daytime.[10] From these, it is likely that the present pump system caught the copepod population swarming near the sea bottom. The number of organisms, however, may be somewhat underestimated, because copepods are able to escape from the mouth of the pump. The present results show an evidence that *A. omorii* forms vertical segregation in each developmental stage maintaining its layers in daytime.

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平戸島志々伎湾で得られたかいあし類 *Acartia omorii* の成長段階別鉛直分布の一例

木　元　克　則

抄　録

1982年3月11日の午後，九州の北西部に位置する平戸島志々伎湾の湾奥の2調査点（海深10.8及び6.3m）において水中ポンプを用いて動物プランクトンを採集した結果，内湾性かいあし類 *Acartia omorii* の全成長段階における極めて明瞭な鉛直分布例を得ることができた。プランクトンは内径40mmのホースを取り付けた水中ポンプにより海面から海底に到る間を0.5m間隔で20 *l* 採取した海水を網目幅 50 μm のナイロンガーゼを張った受けネットでこし取り，*A. omorii* の全成長段階毎に個体数を計数した。

海底が細砂で平坦な地点1では，ノープリアス期幼生（NⅡ から NⅥ）が水深4～5mに中心をもちながら表層から底層にかけて広く分布したが，コペポダイト1期（CI）は4～9mの中層に分布しながらも明らかに海底近くに集中し始め，CⅢ 以降は大部分の個体が海底直上に集中して分布していた。海底にアマモ場が拡がる地点2ではノープリアスは0～5m層に広く分布していたが，CI 以降は底近くの4.5～5.5m層に集中して分布していたことから，*A. omorii* のコペポダイトはアマモ叢の中からやや上方に分布していたと推定される。この2つの分布例から，*A. omorii* は昼間ノープリアスは中表層に分布し，コペポダイトと成体は海底近くに分布し，明らかに成長段階により空間を分けて棲息しているようにみられた。

西水研研報　第66号，昭和63年3月
Bull. Seikai Reg. Fish. Res. Lab., No. 66, March 1988

Direct Observations of Copepod Swarm in a Small Inlet of Kyushu, Japan

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Swarms of copepod were observed and collected by SCUBA diving in Shijiki Bay, southwest of Hirado Island, western Kyushu, Japan, from early spring to midsummer through 1983 to 1985. Copepods were distributed densely just above the sea bottom in daytime forming swarm of various sizes and shapes according to the configuration of sea bottom and season. Nine swarming copepod species, *Acartia omorii, A. steueri, A. sinjiensis, Oithona oculata, O. davisae, Tortanus longipes, T. rubidus, Eurytemora pacifica* and *Pseudodiaptomus nihonkaiensis* were identified. Each swarm consisted of copepodites in various stages, sometimes of a single species and sometimes of a few species. Developmental stage, sex composition, swarming shape and location of these species varied seasonally. Swarms were stationary in the spatial position when the flow of water was weak. There are two processes of swarming on copepods. The first is the increasing of copepod density near the sea bottom in daytime through their diurnal vertical migration, and the second is that of copepods concentrating and forming densely into the lee of bottom materials, thus depending on flow of water that is usually moderate.

INTRODUCTION

Stomachs of red sea bream juveniles are filled with *Acartia omorii* and *A. steueri* in Shijiki Bay, a small inlet of Kyushu, in June.[1] As the mean distributive density of these species is not always high in a water column, it is suggested that copepod are likely to be distributed not randomly, but in swarms.

Copepod swarm, population of densely crowding copepods at the specific spots, had been already reported by some authors. EMERY[2] observed four species of copepods swarm, *Acartia tonsa, A. spinata, Oithona nana,* and *Oithona oculata,* on coral reef. Also, HAMNER and CARLETON[3] observed high dense swarms of *O. oculata, Acartia australis, A. bispinosa,* and *Centropages orsinii,* on coral reefs and eelgrass habitats in tropical waters. They observed that copepod formed swarms according to species and in relation to water conditions. HEBERT *et al.*[4] induced swarming

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of fresh water calanoid copepod *Heterocope septentrionalis* in ponds of Manitoba, Canada. In the temperate and subtropical waters, copepod swarms of 8 species, *Acartia sinjiensis* (as *A. plumosa*), *A. erythraea*, *A. steueri*, *A. japonica*, *A. hamata*, *A. omorii* (as *A. clausi*), *Oithona oculata* and *Labidocera pavo* were observed by Ueda *et al.*[5] He inferred that swarm of copepod was formed according to age and sex, and discussed adaptive functions of swarm.

Tanaka *et al.*[1] suggested that swarm of *A. omorii* and *A. steueri* on the sea bottom must play a major role for the food of juvenile demersal red sea bream in Shijiki Bay. Observations of copepod swarm were made in the Bay in 1978 and 1980 by Ueda *et al.*[5] and Tanaka *et al.*[6] But little is known on copepod swarm in Shijiki Bay and in world seas and lakes as well. The authors have intensively investigated copepod swarms to learn the seasonal changes of distribution, species, developmental stage, sex compositions, copepod density, locality and size of swarm in the various areas in the Bay.

MATERIALS AND METHODS

Direct observation of copepod swarm and collecting of the swarming population was carried out in Shijiki Bay, southwest of Hirado Island, western Kyushu, Japan (Fig. 1), in August 1983, May–July 1984, and April–August 1985. Repeated observations were made by SCUBA diving along 50 m long graduated nylon ropes which were set on sandy bottom and eelgrass (*Zostera marina*) bed of 4 to 13 m depth (L-stations, Fig. 1). The observations were also made at gravelly and sandy bottom and shoal with depth of 6 m to 30 m (S-stations, Fig. 1). Swarms were observed and collected in shallow waters (less than 27 m deep) of Shijiki Bay except in the mouth area of the Bay (Stn. S-9). Swarming copepods were collected with a Van Dorn water sampler (capacity of 6 *l*) and with a newly developed syringe-like Plastic Suction Sampler (3 *l*, Fig. 2a) and a hand operated plankton net (Bilevel SCUBA Plankton Net, 50 cm width and 20 cm height in a mouth flame, 140 cm long with 50 μm mesh cloth, nytal® DIN 110-50, Fig. 2b). The plankton net was operated horizontally for 10 m along the rope by two divers at a speed of about 70 cm per second. The net was kept folded up during descend and was closed during ascend by the divers. Observations were done ordinarily at daytime. In addition, day-night observations were made to clarify the diurnal vertical migration of the copepod. Photographs of swarm and swarming copepods were taken with Nikonos® cameras (Model Ⅲ, Ⅳ and Ⅴ) with 28-mm lens, extension ring (Apollo Co. Ltd.) and flashgun or electronic stroboscopic lamp, and with Asahi Pentax 6×7® camera with macro-135 mm lens and underwater housing.

Collected zooplankton was preserved in seawater formalin solution, and divided

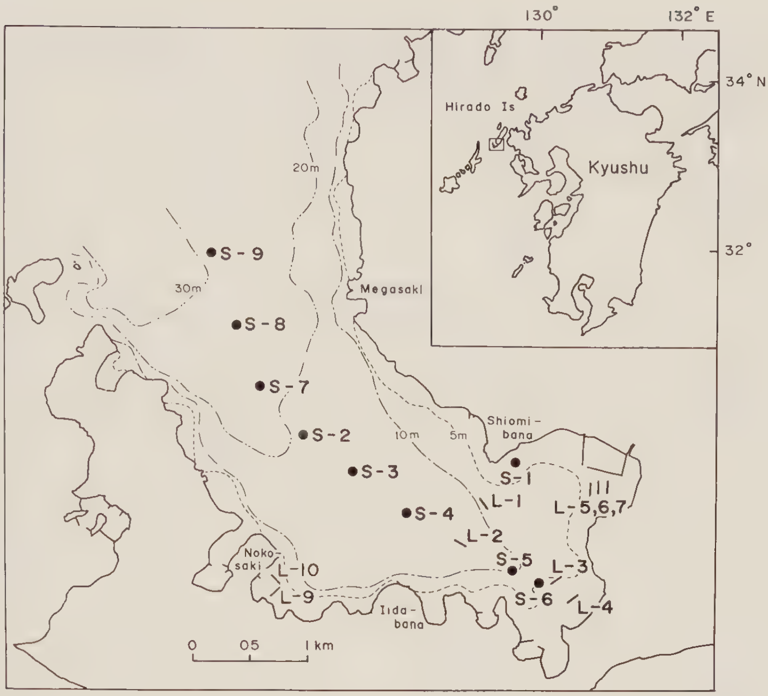


Fig. 1. Location of SCUBA diving stations in Shijiki Bay, southwest of Hirado Island, western Kyushu, Japan. Stations indicated by bar with L- are those where line was set.

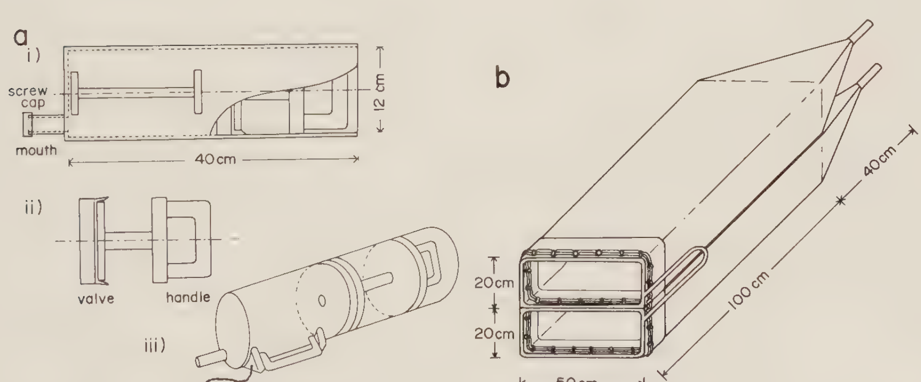


Fig. 2. Copepod collecting instruments.
a : Plastic Suction Sampler.
i) Transparent plastic cylinder with a volume of 3*l*, lateral
ii) Piston with valve of leather cloth, lateral
iii) Perspective of the sampler
b : Bilevel SCUBA Plankton Net. 50 μm mesh monofilament nylon screen cloth (nytal® DIN 110-50), hand-operated, kept folded up during descend and closed during ascend by the divers.

into 2-400 aliquots using a box type plankton sample spliter and a large mouthed pipette. The number of individuals was counted according to developmental stages (naupliar stages and copepodite stages) and sex. *Acartia steueri* was distinguished from *A. omorii* by the presence of rostrum filaments[6,7] in the stages of copepodite stage II (CII) to stage VI (CVI), but was not distinguished in the naupliar stages (N) and CI.

COPEPOD SWARMS AND THEIR CHARACTERISTICS

Copepods collected from a swarm with water sampler generally contained small numbers of non-swarming planktonic, or epibenthic copepods. But swarming copepods far outnumbered them. Copepod nauplii were scarce in the swarms. Nine swarming copepod species were identified in the Bay; 3 species of *Acartia* (*A. omorii*, *A. steueri*, *A. sinjiensis*), 2 species of *Oithona* (*O. davisae*, *O. oculata*), 2 species of *Tortanus* (*T. longipes*, *T. rubidus*), *Eurytemora pacifica* and *Pseudodiaptomus nihonkaiensis*. Swarm consisted of copepodites in various stages of a single species, and sometimes of a mixture of several species of one or two genera. Species, stage and sex composition, shape of swarm and swarming location showed seasonal variation (Fig. 3, Table 1).

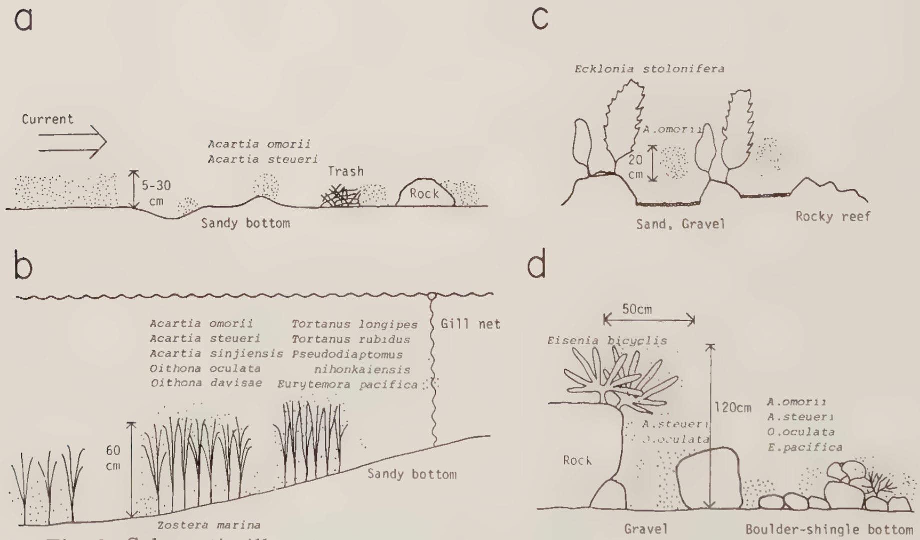


Fig. 3. Schematic illustrations of copepod swarming according to bottom topography and materials in Shijiki Bay.
a : Sandy bottom b : Eelgrass (*Zostera marina*) bed
c : Shoal of small rocks with brown algae
d : Shoal of large rocks with brown algae

Table 1. Copepod swarms observed by SCUBA diving in Shijiki Bay, through 1983 to 1985. Data marked *, and ** are described in latter tables in detail. Bold types are meant copepod species **A.o.** ; *Acartia omorii*, **A.s.** ; *Acartia steueri* **A.si.** ; *Acartia sinjiensis*, **O.d.** ; *Oithona davisae* and **O.o.** ; *Oithona oculata*, respectively.

Swarming location and species	Shape and size of swarm	Depth (m)	No. of samples examined	Density of copepodites (nos./ℓ)	Adults to copepodites ratio(%)[a]	Females to adults ratio(%)
Over flat sandy bottom						
Acartia omorii	Continuous flat swarm, 5-30cm thick	10-27	9	15-156	26.6 91.0	24.5-96.7
A. omorii+*A. steueri*	Irregular balls, 10 30cm in diameter	10 24	2	237-484	65.2-81.5	66.3-90.5
	Continuous flat swarm, 5 30cm thick	10-18	10	10-343	**A.o.** 30.8-85.2	45.8-78.8
					A.s. 31.6-88.4	2.8-85.3
	Irregular balls, 10-50cm in diameter	10-13	3	72-132	**A.o.** 23.1-62.3	42.9-87.4
					A.s. 63.2-79.2	44.3-63.5
Over and throughout entire eelgrass beds						
A. steueri	Irregular balls, 10-50cm in diameter	2 7	13	43-404	33.9-99.1	65.5-98.1
A. omorii+*A. steueri*	Irregular balls, 10-50cm in diameter	7	3	24 47	**A.o.** 75.0-76.2	62.5-83.3
					A.s. 70.1-87.5	15.9-60.0
A. omorii+*A. steueri*+ *Pseudodiaptomus nihonkaiensis*	Cushion like, 50cm thick	3	4	*	*	*
A. omorii+*A. steueri*+ *Eurytemora pacifica*	Irregular balls, 20cm in diameter	4	2	**	**	**
Oithona oculata	Irregular balls, 10-30cm in diameter	4-5	4	821-6493	4.8-80.2	48.2-66.0
Edge of eelgrass bed						
A. steueri	Irregular balls, 10cm-1m in diameter	2-6	8	50-744	27.4 100.0	1.8-99.6
A. steueri+*O. davisae*	Irregular balls, 50cm-1.5m in diameter	3	3	**A.s.** 9-114	44.4-96.8	80.0-97.0
				O.d. 72 219	12.4 24.7	19.7-71.3
A. sinjiensis+*O. oculata*	Spherical, 10cm in diameter	4	1	**A.si.** 55	91.7	33.0
				O.o. 46	47.3	55.8
A. omorii+*A. steueri*+ *P. nihonkaiensis*	Irregular balls, 10-30cm in diameter	4-6	2	*	*	*
Tortanus longipes+*T. rubidus*	Column, 20cm in diameter, 50cm in height	2	1	15 copepodites were collected		
Over rocky shore, gravelly bottom and around algal beds						
A. omorii	Irregular balls, 10-20cm in diameter	15-20	11	13-218	32.6-94.3	35.6-84.4
A. omorii+*A. steueri*	Irregular balls, 10cm-3m in diameter	2-7	20	53-1235	**A.o.** 47.5-94.2	18.0-65.0
					A.s. 21.3-93.5	19.1-89.7
A. omorii+*A. steueri*+ *E. pacifica*	Irregular balls, 10cm-1m in diameter	4	4	**	**	**
O. oculata	Irregular balls, 10-50cm in diameter	2-7	9	490-4683	3.2-67.0	20.9-65.7

[a]) Obtained by omitting CI on *Acartia omorii* and *Acartia steueri*

Swarms at sandy flat bottom: *A. omorii* formed continuous flat swarm of 5 to 30 cm thick just above the flat sandy bottom from mouth area to inner part of the Bay with depths 5 to 27 m (Stns. L-1, 2, S-3, 5, 7, 8) (Fig. 3a, Plate 1A). *A. steueri* also formed continuous flat swarms together with *A. omorii* from middle area to inner part of the Bay (Stns. L-1, 2, S-3, 5). Thickness and density of copepod swarm varied from one place to another, and may be affected by the small-scale configuration of sea bottom and strength of flow of water. Copepods sometimes formed small ball or disk-shaped swarm just above the bottom. The size of disk-shaped swarms ranged from 10 cm to a few meters in diameter. The boundary between the swarms and its surroundings, however, was not always discrete in the present environment.

Acartia swarms with clear boundary were observed in the lee of bottom materials just above the sandy bottom. The material consisted of clumps of alive or dead seaweeds, rock, trash, etc. (Plate 1B, C, D). In addition, copepod swarm was often formed in a hollow and above a small swell of sandy bottom. The size of

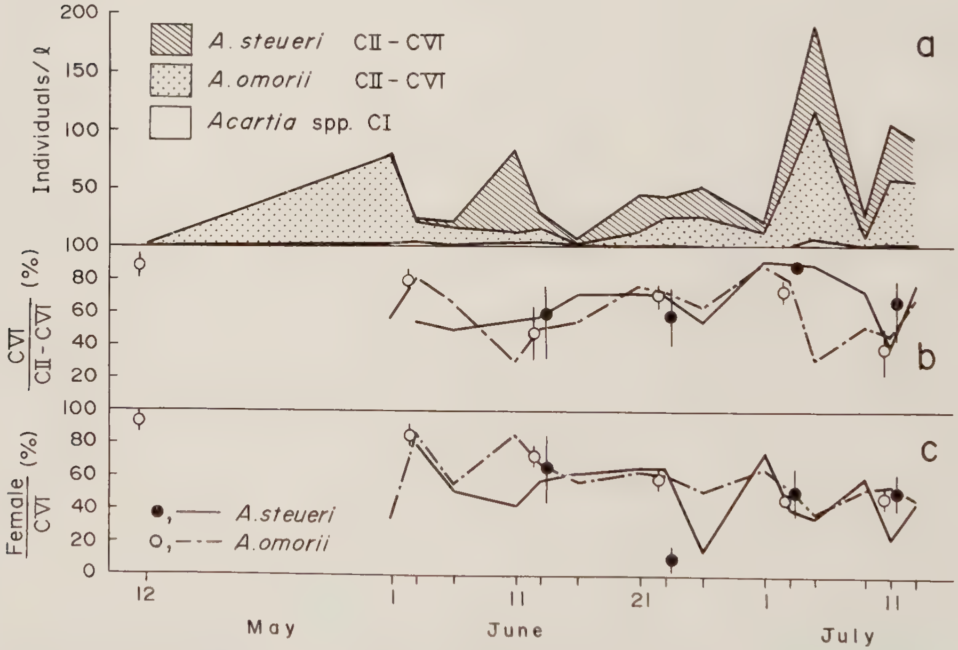


Fig. 4. Seasonal changes of the number of *Acartia steueri* and *A. omorii* (a), percentages of adults(b) and percentages of females in each species of *Acartia*(c) collected by horizontal tow with Bilevel SCUBA Plankton Net between 0 to 20 cm layers above the bottom (solid and broken lines) and mean ratios collected by the Van Dorn water sampler (●, ○) on flat sandy bottom of inner part of Shijiki Bay, from 12 May to 13 July 1984. Vertical lines in (b) and (c) show the range.

such swarms ranged from about 10 to 50 cm in diameter. It was observed that swarming copepods usually kept the spatial position and direction against a moderate flow of water. But when the velocity of the flow was higher than about 5 cm/sec., copepods were carried away by the flow forming a loose swarm.

The number of individuals of the whole copepodite stage of *A. steueri* and *A. omorii* in swarms, collected by horizontal net towing between 0 and 20 cm layers above the bottom at Stn. L-1, showed a peak of 188 per liter of sea water in early June, and 57 in mean through the period of observation (Fig. 4a). *A. omorii* occupied major part of the *Acartia* swarms during April to early June, and it was replaced by *A. steueri* after mid-June. The ratio of the number of adults to the copepodites (CII to CVI) of two species varied seasonally, but kept at about 60 percent in mean during the observational period (Fig. 4b). Females occupied 58.4 % (ranged from 35.6 to 86.3%) of adult forms in *A. omorii* and 51.0% (ranged from 14.6 to 79.2%) in *A. steueri* during May to July (Fig. 4c). The density of copepodites collected by the Van Dorn water sampler ranged from 10 to 343 per liter during the same period. Composition of copepod species and developmental stages, and sex ratio obtained by a water sampler were similar to those of net collections (plots in Fig. 4b, c).

Swarms at eelgrass bed: Eelgrass (*Zostera marina*) grow thick and form eelgrass bed in the innermost part of the Bay (Stns. L-3, 4, 7, 9, 10, S-1) with a depth of sea bottom ranging from 2 to 7 m. *A. omorii* and *A. steueri* formed swarms of dif-

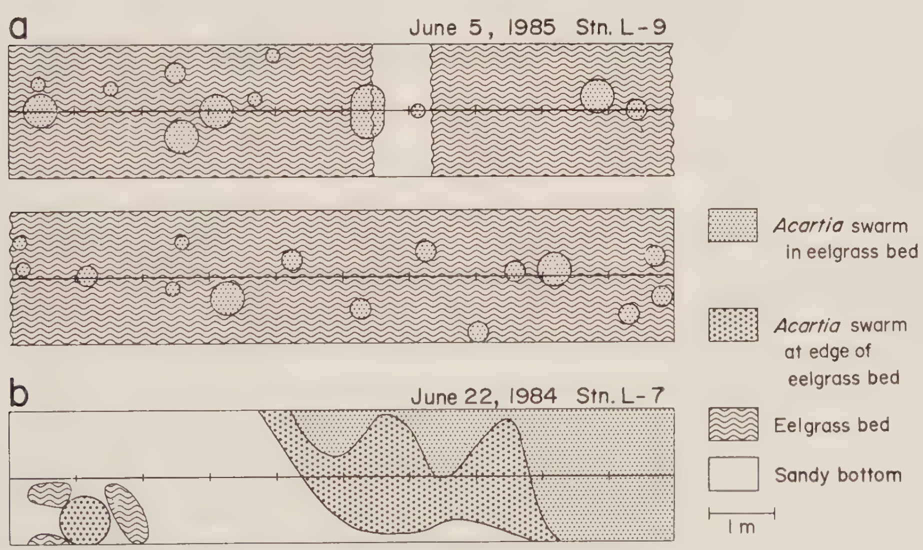


Fig. 5. Horizontal distribution of *Acartia steueri* swarms obtained by eye observation along the transect line set in the eelgrass bed (a: in the area of 20m×2m) and edge of the eelgrass bed (b: in the area of 10m×2m) of inner part of Shijiki Bay. Each circle shows a rough size of swarm of *A. steueri*.

ferent shape according to the shape of the bed (Fig. 3b). Ball-shaped swarms of *A. omorii* and *A. steueri* with a diameter from 10 to 50 cm keeping a distance of about 10 to 30 cm above the bottom, and column-shaped swarms with a diameter 10 to 30 cm and 40 cm to 1 m height just above the bottom, were patchily distributed at openings of the eelgrass bed depending likewise on the size of the openings, during April to July (Fig. 5a). When copepods were abundant each swarm grew large and copepods were distributed continually throughout the eelgrass bed and above the grass blades, the later forming a cushion like layer of about 20 cm (Plate 1E, F).

Density of both adults and copepodites of *Acartia* ranged from 13 to 341 per liter collected by the horizontal net towing inside the swarm between 20 to 40 cm layers above the bottom at Stn. L-4 (Fig. 6a). The majority of the population consisted of *A. steueri*. The ratio of adults to copepodites in *A. steueri* (CII to CVI) was rather high, and increased from May to July (min. 24.2%, max. 99.4%) (Fig. 6b). The ratio of females to adults was as high as about 60 percent until late June, and increased to 80 percent or more in July (Fig. 6c). Swarms collected by

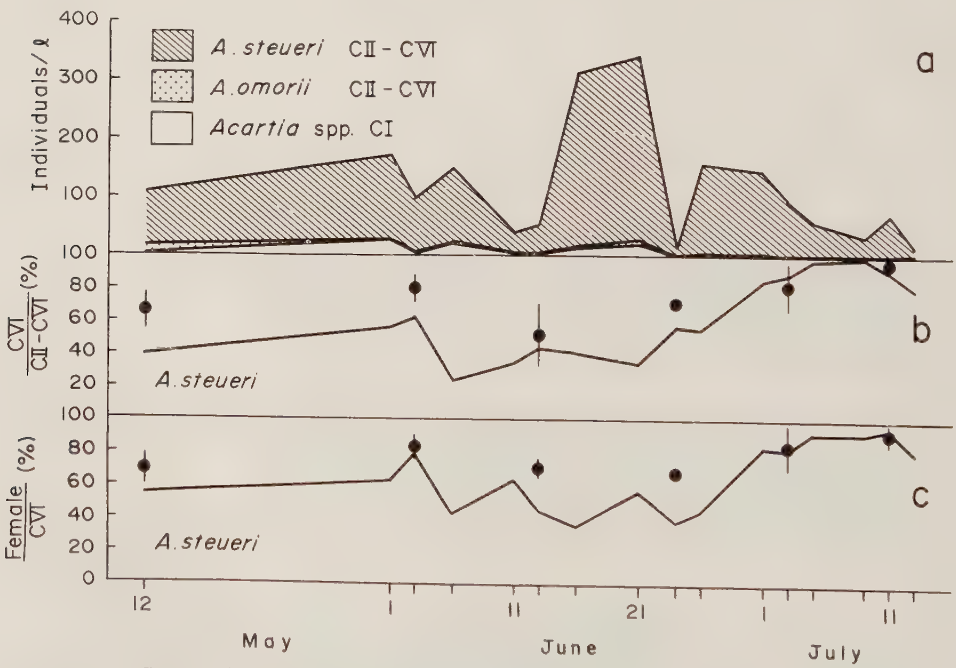


Fig. 6. Seasonal changes of the number of *Acartia steueri* and *A. omorii*(a), percentages of adults(b), and percentages of females of *A. steueri*(c) collected by horizontal tow with Bilevel SCUBA Plankton Net between 20 to 40 cm layers above the bottom (solid line) and mean ratios collected by the Van Dorn water sampler (●) inside eelgrass (*Zostera marina*) bed of inner part of Shijiki Bay, from 12 May to 13 July 1984. Vertical lines in (b) and (c) show the range.

a water sampler, after June, consisted of a single species of *A. steueri*. The density of copepodites ranged from 43 to 404 per liter by the water sampler. The ratio of adults to copepodites (CII to CVI) and females to adults in swarms obtained by the water sampler was higher than those obtained by net collections (plots in Fig. 6b, c).

Many swarms of *A. steueri* were often observed along the edges of eelgrass beds, with about 10 to 100 cm width, and in spaces surrounded by small assemblages of eelgrass. However, no swarm was observed on sandy bottom a few meter away from the eelgrass bed (Fig. 5b). Density of organisms in these swarms was also high ranging from 79 to 358 per liter (5 samples). The ratio of adults to copepodites (CII to CVI) and that of females to adults were high, although, the authors obtained an exceptional swarm consisting of male and young copepodites. It was collected on June 5, 1985, and was a dense swarm of about 1 m in diameter formed above a trash of dead eelgrass blades gathered surround a rock (about 50 cm wide, 30 cm length and 30 cm high), in which adult male far outnumbered adult females (total 744 copepodites, 198 CVI males and only 4 females per liter).

A small cylindrical swarm of copepods (about 20 cm in diameter, 50 cm in height) consisting of several dozens copepods belonging to two species of *Tortanus* was observed above sandy bottom of 2 m in depth about 50 cm away from the eelgrass bed on June 24, 1984. We could collect only 15 individuals by the Van Dorn water sampler from the swarm. Copepods were 2 CVI males of *T. longipes*, 1 CVI male of *T. rubidus* and 12 immature copepodites (7 CV females and 5 CV males). In the swarm, organisms moved swirly and kept up a cylindrical form.

Three irregular ball-shaped swarms consisting of *A. steueri* and *O. davisae* in the ratio between 1 : 1.5 and 1 : 7.0 were observed on sandy bottom along the edge of eelgrass bed on July 3, 1984. The largest swarm measured 1.5 m in the long axis, 1 m in width and 0.5 m thick.

After July, when the temperature of sea water exceeded 25℃, *A. omorii* and *A. steueri* disappeared, and *O. oculata* appeared and formed swarms. Ball-shaped swarms with a diameter of 10 to 30 cm consisting of copepodites of *O. oculata* were observed keeping a distance of about 30 cm from the sandy bottom at opening inside eelgrass bed (Plate 2A), and near the roots of the edges of eelgrass beds on sandy bottom (Plate 2B) at the inner part of the Bay. The boundary of these swarms was very clear. The density of organisms in a swarm of *O. oculata* was higher than that of *Acartia*, ranging from 821 to 6493 per liter (4 samples). The ratio of adults to whole copepodites of *O. oculata* swarms ranged from 4.8 to 80.2%, and females to adults was about a half (mean 54.3%, ranged from 48.2–66.0%). On a sunny day of August 14, 1985, a spherical swarm about 10 cm in diameter consisting of *Acartia sinjiensis* and *O. oculata* in a ratio of 1 : 0.8 was observed at an opening in

the eelgrass bed, keeping a distance of about 30 cm above the sandy bottom.

Swarms in shoals: In the lee of small rocks and blades of brown alga *Ecklonia stolonifera* on shoal in the central part of the Bay with depths of 15 to 20 m (Stns. S-2, 4, Fig. 3c), ball-shaped swarms of *A. omorii* with a diameter ranging from 10 to 20 cm, keeping a distance of about 10 to 20 cm from sandy or gravelly bottom were observed during the observational period. The boundary of these swarms was more clear than those of swarms formed at sandy bottom. The number of organisms of the swarms ranged from 13 to 218 per liter (11 samples). On the other hand, on shoal near the shore, in the inner part of the Bay with depths of 2 to 7 m (Stns. S-6, L-5, 6), *A. steueri* and *A. omorii* formed big and dense swarms in the lee of large rocks and blades of brown algae *E. stolonifera*, *Eisenia bicyclis*, and roots of *Sargassum* spp. (Fig. 3d, Plate 2C). It was observed that copepods in these swarms kept direction swimming against the flow of water (Plate 2D). *O. oculata* formed dense and ball-shaped swarms in the lee of small and large rocks similar to the swarms formed on eelgrass bed, on July and August. Their diameter ranged form 10 cm to 50 cm. The number of swarm organisms was high, ranging from 490 to 4683 per liter (9 samples).

Swarms of *Acartia* and *Oithona* observed on the eelgrass bed and shoals were diverted right and left by water movement or by diver's disturbance. But they quickly resumed their initial position when the water movement ceased. The authors observed once a swarm of *A. steueri* also around artificial materials, *i. e.*, an assembly of gill net for crab fishing set on sandy bottom near the shore with a depth of 2 m (Plate 2E). The copepods were swimming downward, against the flow of water, and maintained their spatial position (Plate 2F).

Six ball or disc-shaped swarms of *A. omorii*, *A. steueri* and *Eurytemora pacifica* with a diameter range from 10 to 100 cm and 20 cm thick were observed at the eelgrass bed and boulder-shingle bottom in the inner part of the Bay on May, 1984. These swarms were formed keeping a distance of about 50 cm above the bottom. Those collected with the Van Dorn water sampler, have their densities and stage composition shown in Table 2. Also on July 10-13, 1984, 6 samples were collected from dense swarms distributed throughout on eelgrass bed and on sandy bottom at the edges of eelgrass bed in the inner part of the Bay (Table 3). These swarms consisted of *A. omorii*, *A. steueri* and *Pseudodiaptomus nihonkaiensis* and some epibenthic copepods.

DISCUSSION

The present results show that copepod formed swarm closely related to the micro-bottom topography, and other materials on the bottom. Irregular ball shaped

Table 2. Densities (individuals per liter) and stage composition of swarms consisted of *Acartia* and *Eurytemora* at eelgrass bed of 4 m deep (Stn. L-4) (sample Nos. 1 and 2) on May 12, 1984 and boulder-shingle bottom of 4 m deep (Stn. L-6) (sample Nos. 3 to 6) on May 13, 1984.

Species and developmental stage		Eelgrass bed		Boulder-shingle bottom			
		1	2	3	4	5	6
Acartia spp.	total	**314.5**	**275.3**	**208.5**	**139.4**	**91.1**	**74.2**
Acartia spp.	C I	9.3	9.7	35.4	5.7	8.9	6.8
Acartia omorii	C II	6.1	1.3	5.7	4.1	4.6	3.6
	C III	12.7	6.4	7.9	5.9	1.6	2.2
	C IV	17.2	4.0	6.7	7.2	0.6	1.1
	C V	24.8	3.5	7.4	10.1	0.7	1.7
	C VI ♂	24.8	3.5	4.0	4.9	0.2	0.2
	C VI ♀	45.4	9.9	5.7	10.0	0.5	0.2
Acartia steueri	C II	17.6	23.2	18.9	12.2	6.3	1.6
	C III	8.8	23.8	12.4	22.2	7.0	1.9
	C IV	5.1	26.7	4.0	16.6	2.7	0.8
	C V	9.1	33.2	4.6	9.8	1.9	2.0
	C VI ♂	28.5	51.2	40.2	29.7	13.0	40.8
	C VI ♀	105.2	78.9	55.7	1.0	43.2	11.5
Eurytemora pacifica	total	**69.9**	**56.9**	**83.3**	**47.6**	**48.2**	**33.0**
	C I	1.3	0.8	18.6	2.8	1.3	1.1
	C II	2.5	1.8	12.5	10.4	1.3	2.2
	C III	9.6	3.9	11.5	13.2	2.7	2.3
	C IV	17.5	12.4	17.0	15.7	16.7	7.9
	C V ♂	12.7	10.7	9.2	4.4	9.7	5.6
	C V ♀	15.8	19.0	4.6	0.3	7.9	5.8
	C VI ♂	9.3	6.5	9.4	0.7	7.1	6.8
	C VI ♀	1.2	0.7	0.6	0	1.5	1.2
Epibenthic cyclopoids		**1.9**	**0.5**	**10.0**	**1.2**	**10.9**	**5.0**
Epibenthic harpacticoids		**10.9**	**8.1**	**41.4**	**2.8**	**12.7**	**10.0**
Other copepods		**6.6**	**8.1**	**9.1**	**4.0**	**7.0**	**6.4**

swarms were often formed in hollows and above swells of sandy bottom, throughout the eelgrass bed, and in the lee of seaweeds and some materials on the bottom (Fig. 3). Species and stage composition of swarm may depend on the reaction of species to the bottom topography and weak water flow in these swarming sites.

It is suggested that there are two processes of swarming in copepods. The first process is an increase in copepod density near the sea bottom during the day through diurnal vertical migration. Thus swarms of copepod formed according to the diurnal rhythm of organisms, *i.e.*, immediately after sunset, copepods of the *Acartia* swarms swam upward with a spiral movement, dispersing the swarm throughout the water column. After sunrise of the next morning, they swam downward

Table 3. Densities (individuals per liter) and stage composition of swarms consisted of *Acartia* and *Pseudodiaptomus* at eelgrass bed of 4 m deep (Stn. L-4,7) (sample Nos. 1 to 4) and sandy bottom near the eelgrass bed of 4 to 6 m deep (Stn. S-1, L-3) (sample Nos. 5 and 6) on July 10-13, 1984.

Species and developmental stage		Eelgrass bed				Sandy bottom near the eelgrass bed	
		1	2	3	4	5	6
Acartia spp.	total	**75.5**	**325.2**	**112.2**	**169.2**	**285.8**	**39.7**
Acartia spp.	C I	0.2	0	0.8	0	0.3	0.6
Acartia omorii	C II	0	0	3.0	0	0	0
	C III	0	0	5.8	0	0	0.2
	C IV	0	0.2	6.8	0	1.8	0.3
	C V	0	0.2	2.6	0	0.6	0.6
	C VI ♂	0	0	12.5	0	0.9	1.4
	C VI ♀	0	0	4.1	0.3	0.9	1.2
Acartia steueri	C II	0.8	0.2	3.8	0	6.3	0.9
	C III	1.4	3.7	6.7	0.2	23.7	0.3
	C IV	2.3	5.5	4.8	0.5	31.6	1.4
	C V	2.4	5.4	3.2	0.9	30.3	0.5
	C VI ♂	7.8	35.0	12.0	2.8	149.8	10.0
	C VI ♀	60.7	275.2	46.1	164.5	39.6	22.4
Pseudodiaptomus	total	**86.1**	**55.2**	**17.3**	**16.2**	**16.8**	**12.9**
nihonkaiensis	C I	4.7	1.2	3.2	0.6	1.5	1.8
	C II	3.1	3.1	4.4	0.3	0.9	1.8
	C III	16.5	5.4	1.4	2.2	2.7	2.9
	C IV	20.3	15.8	1.4	5.2	3.7	2.4
	C V ♂	13.6	9.3	1.2	1.8	1.6	1.2
	C V ♀	10.4	6.1	1.8	1.6	1.2	0.8
	C VI ♂	6.1	7.0	1.7	2.8	3.4	1.1
	C VI ♀	5.2	7.4	2.3	1.6	1.6	0.9
Epibenthic cyclopoids		**23.6**	**14.4**	**18.4**	**0**	**9.3**	**6.4**
Epibenthic harpacticoids		**221.1**	**190.2**	**73.4**	**39.1**	**1.2**	**191.1**
Other copepods		**11.5**	**6.3**	**53.0**	**6.5**	**3.3**	**6.4**

and formed the swarms again on the sea bottom. The second process is that of copepods swimming near the bottom concentrating and forming a much denser swarm into the lee of materials. One of the authors proved this by inducing copepod swarm by setting plastic boxes with different sizes on flat sandy bottom in the Bay (KIMOTO unpublished). The maintaining of spatial position for copepod swarm may be caused by the wake formed behind the materials on the bottom. This interpretation was made by KAKIMOTO *et al.*[10] They observed copepod (*A. clausi*) and mysid (*Proneomysis fasca*) swarms at natural and artificial reefs in the coastal area of Niigata Pref., Japan Sea. Copepods which are gathered in a

certain density may be able to recognize other individuals by chemical,[11] optic and physical stimuli, and may maintain a swarm well and fulfill other functions.

In Shijiki Bay, swarm consisted of many copepodite stages, sometimes of a single species but also of a mixture of several species of the same or another genera. Copepods of *Acartia* and *Oithona* swarming during the day aggregated in several hundreds times as dense as mean density of water column (less than 10 copepodites per liter[9]). The density of swarms changed not only seasonally, but also day by day. It is probable that unstableness of density of swarm was caused by change of season, and weather or tidal current conditions of every day. Females of adult *A. steueri* seem to be gathered or crowded in swarm on eelgrass bed, because the percentage of adult females to copepodites in swarm collected by the water sampler was much higher than that collected by horizontal tow inside swarms by hand operated plankton net, during May to June (Fig. 6). Although there is no certain evidence that swarm is formed sex-specific, because adult females of *A. steueri* at sandy bottom did not likely gather at same period (Fig. 4). The high percentage of female may be due to seasonal change and the long life of females in July.

Adaptive functions of copepod swarm were suggested by previous authors.[2-5,12,13] Hamner and Carleton[3] suggested four adaptive functions caused by copepod swarming; protection from predators, facilitating of breeding, maintaining a favorable position to feed on coral mucus, and restricting dispersion by currents. They suggest that protection from predators was most common and an important adaptive explanation for copepod swarming, and that a combination of advantages was responsible for the populations in coral reefs. The importance of these functions may vary according to species. Reduction of dispersion by currents appears to be of major importance for the swarms in maintaining the populations of copepods, as Ueda *et al.*[5] and other previous authors had already pointed. But the authors have no information to conclude the adaptive functions of the swarm. On the other hand, there is a certain contradiction in swarming. It is that swarming organisms are vulnerable to get round up by demersal fishes. Predation on *A. steueri* and *A. omorii* by demersal juveniles of red sea bream was observed in the Bay.[1] Therefore, adaptive function of swarm must have a different explanation. This can be done only after the investigations of diurnal rhythm of feeding, excretion and spawning of swarming copepods.

When an early demersal juvenile of fish with weak swimming power was led by the flow of water to a copepod swarm formed at a specific position, the juvenile may be able to encounter and feed effectively on swarming copepods. The maximum number in the stomach of a 15 mm demersal juvenile of red sea bream was about 200 copepods of *Acartia*.[1] The juvenile can get sufficient food only in a swarm of

one liter, because copepods are ordinarily distributed two hundred individuals per liter. Therefore, copepod swarming is important as food strategy for red sea bream and some fishes during their early demersal life. The copepod swarm can be induce by properties of artificial structure on the sea bottom, and it may be possible to design a new nursery ground for juveniles of fishes in the future.

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平戸島志々伎湾におけるかいあし類スオームの潜水観察

木元　克則・中嶋　純子・森岡　泰啓

抄　　録

1983年8月，1984年5月～7月および1985年4月～8月にわたり，九州の北西部に位置する平戸島志々伎湾内でスクーバ潜水し，かいあし類のスオームの観察と採集を行った．かいあし類は昼間，海底直上に分布し，海底の形状に応じてスオームを形成した．スオームをつくるかいあし類は，*Acartia* 属3種（*A. omorii, A. steueri A. sinjiensis*）と *Oithona* 属2種（*O. oculata, O. davisae*），*Tortanus* 2種（*T. longipes T. rubidus*），*Eurytemora pacifica* 及び *Pseudodiaptomus nihonkaiensis* の9種であった．これらのスオームは1種，あるいは数種のかいあし類のさまざまな成長段階のコペポダイトで構成されていた．種組成，成長段階組成，性比，スオームの形状，及び形成される場所は季節的に変化した．スオームは水の流れが弱いときには，空間的分布位置を変えることなく形成された．また，海底の岩，寄り藻，底生生物が噴出した砂山，窪み，刺網，ごみの周囲にもしばしば形成された．湾内のスオームの分布，形成状況から，かいあし類のスオームは，昼夜の鉛直移動と流れにより海底の特定な場所に集積し，維持された結果と考えられた．

EXPLANATION OF PLATE

Plate 1

A : Crowded population of *Acartia omorii* and *A. steueri* just above the flat sandy bottom with depth 11 m in Shijiki Bay, July 3, 1984.

B : A swarm of *Acartia omorii* and *A. steueri* in a lee of clump of algae on flat sandy bottom with depth 13 m in Shijiki Bay, June 2, 1984. Water flowed from right to left side in the photograph.

C : A swarm of *Acartia steueri* in a lee of clump of algae on flat sandy bottom with depth 7 m in Shijiki Bay, July 3, 1984.

D : *Acartia steueri* swarm in a lee of clump of trash and dead algae at flat sandy bottom with depth 7 m in Shijiki Bay, June 5, 1985.

E : *Acartia steueri* swarm inside and above eelgrass (*Zostera marina*) bed with depth 4 m, inner part of Shijiki Bay, July 3, 1984.

F : Copepodites of *Acartia steueri* swarming above and among the blades of eelgrass (*Zostera marina*) with depth 4 m, inner part of Shijiki Bay, July 3, 1984.

Plate 2

A : A ball-shaped swarm of *Oithona oculata* with a diameter of about 20 cm keeping a distance about 30 cm above the sandy bottom at opening inside eelgrass (*Zostera marina*) bed with depth 5 m, inner part of Shijiki Bay, August 1, 1983.

B : A ball-shaped swarm of *Oithona oculata* with a diameter of about 10 cm near the roots of eelgrass (*Zostera marina*) at 7 m in depth, inner part of Shijiki Bay, August 14, 1985.

C : A swarm of *Acartia steueri* surrounding a rock and algae at near shore shoal with depth 6 m in Shijiki Bay, July 10, 1984.

D : Copepodites of swarming *Acartia steueri* swimming in the same direction at near shore shoal with depth 6 m in Shijiki Bay, July 10, 1984.

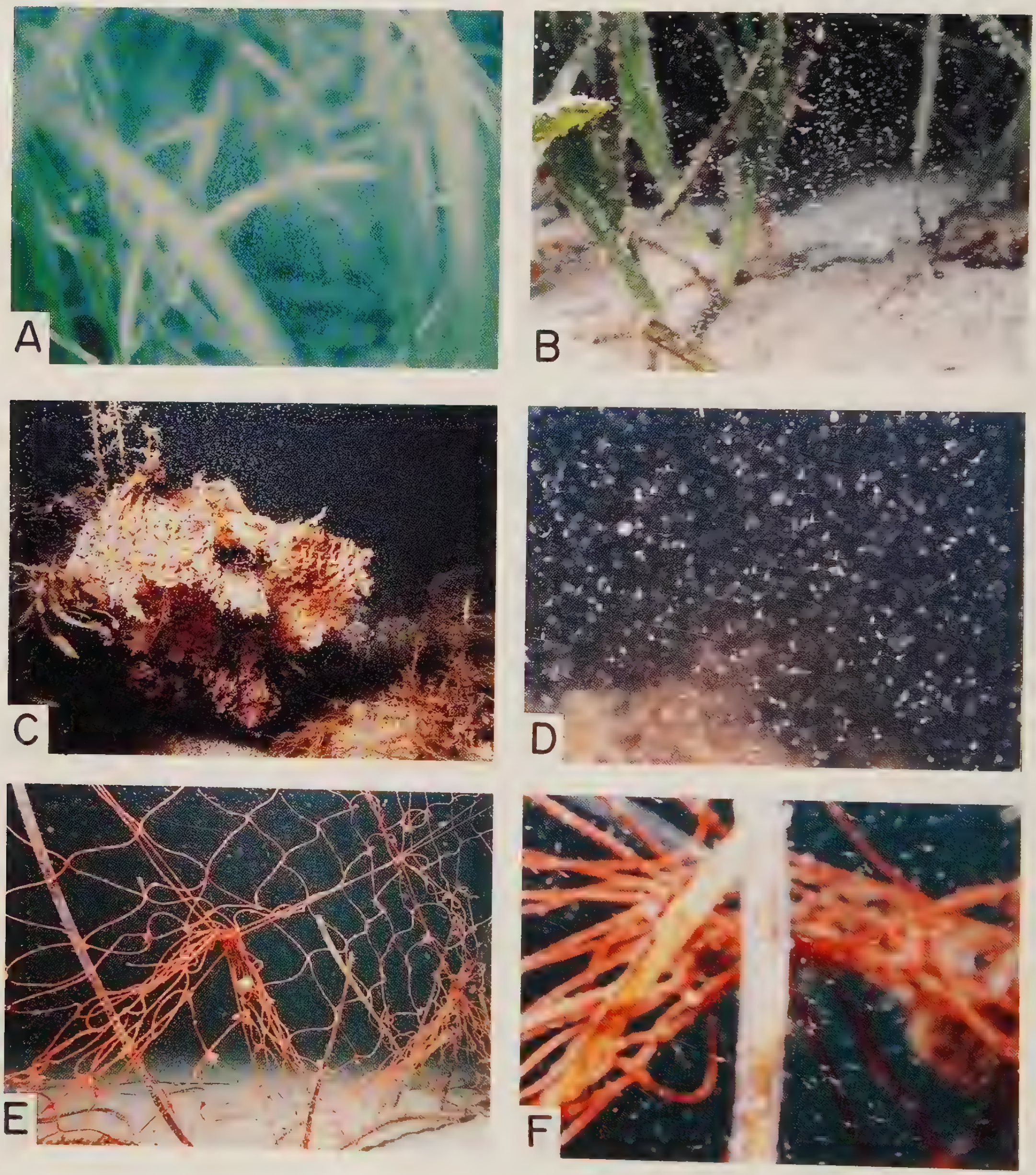
E : *Acartia steueri* swarming at a gill net assembly for crab fishing set on flat sandy bottom with depth 2 m in Shijiki Bay, July 11, 1984.

F : Copepodites of swarming *Acartia steueri* swimming against flow of water at a gill net, July 11, 1984. Water flowed from right to left side in the photograph.

Plate 1



Plate 2



超音波式潮流計による残差流の測定

加 藤 修*

Measurement of Residual Current Using the Doppler Sonar

Osamu KATOH*

To estimate the residual current component across the Tsushima eastern channel, the continuous measurement was carried out using the doppler sonar in June, 1987. The survey was repeated four times during 24 hours and 50 minutes along the observation line within the same time interval to eliminate diurnal and semidiurnal tidal component.

In the Tsushima island area SW-WSW direction residual current component was dominant in the layer from surface to 50 m depth. In the other area, the flow direction was NE-ENE except part of the coastal waters of Fukuoka Pref., where residual current was scarcely measured.

This survey method was found applicable to observation of the distribution of residual current.

緒 言

九州北岸から山陰沿岸にかけては海域全体が好漁場であるとともに主要航路にあたるため，係留系による流れの観測は非常に困難である．そのため当海域での流れに関する情報は少ない．

近年，超音波式潮流計が実用化され，GEK に代わる測器として多くの機関で使用されはじめている．またその有効性や精度に関して多くの報告がなされており[1-5]，係留系による調査が困難な海域での流況観測には超音波式潮流計が有効であると考えられる．

沿岸域での流れは潮流とそれ以外の流れ（残差流）の和とすることができるが，卵・稚仔の輸送や海流の構造を明らかにする上で平均的な流況，すなわち残差流の分布を知ることが必要となる．そのためには，測流結果から潮流の影響を除去することが可能となる新しい流況観測方法の導入が不可欠である．

筆者は1987年6月上旬に対馬東水道（Fig. 1）において同一コースを24時間50分で4往復する方法での流況観測を試みた．本報告では，その結果をもとに対馬東水道での流況について述べる．そして今回の方法によって求められた残差流の測定精度について検討し，この方法が平均的な流況を把握する上でどの程度有効であるかについて考察を行った．

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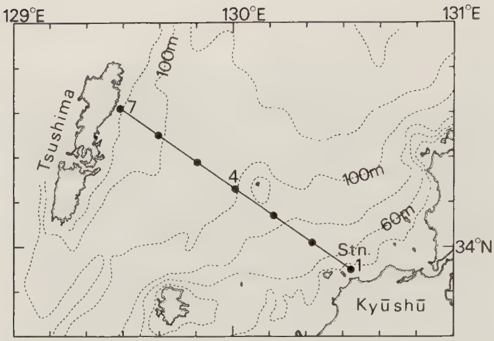


Fig. 1. 流況観測のための調査定線（1987年6月3日—7日） 地点1—7については Fig.3 参照
Cruise transect for current measurement, June 3–7, 1987 (see Fig.3 for Stn. 1–7).

本調査を進めるにあたり乾 栄一船長をはじめとする調査船陽光丸（西海区水産研究所 所属 499トン）の乗組員の皆様に多大な御助力をいただいた。特に築山一雄一等航海士には調査設計から実行段階に至るまで非常に貴重な助言をいただいた。ここに厚く感謝を申し上げる．

また本報告の取りまとめにあたり懇切な御教示をたまわった京都大学農学部坂本亘助教授に心より御礼を申し上げる．

最後に本稿の校閲を頂いた竹下貢二下関支所長，林小八同第一研究室長に深謝の意を表する．

なお本研究は漁業資源評価システム高度化調査の一環として調査船陽光丸に装備されている超音波式潮流計（古野電気 CI-30）で実施した．

観測およびデータ処理方法

1） 本報告における残差流の定義

潮流は日周潮流（周期24時間50分）と半日周潮流（周期12時間25分）の2つから成り立つと仮定する．ここで24時間50分で同一区間を4往復航行する場合を考える（Fig. 2)．P1 から P3，P2 から P4，P5 から P7 及び P6 から P8 に航行するのにそれぞれ6時間12分30秒を要する．半日周潮流だけを考えれば P1 と P3，P2 と P4，P5 と P7 及び P6 と P8 のそれぞれ両地点では6時間12分30秒ずれるため逆位相となる．したがって地点Pで1—8回の半日周潮流の成分を合計すれば 0となる．同様に日周潮流についても P1 と P5，P2 と P6，P3 と P7 及び P4 と P8 の変化は互いに12時間25分ずつずれているので逆位相となり，1—8回の日周潮流の成分を合計すれば0となる．したがって潮流が日周潮流と半日周潮流の和であるとの仮定のもとでは，地点Pでの1—8回の観測値を合計すれば潮流の影響が除去できる．以上のような考えのもとに1—8回の観測値の平均値から求めた流れを残差流とした．実際には，潮流は日周，半日周潮流以外の分潮成分も含んでおり，また地形の影響も受けるから上記の方法を用いたとしても潮流の影響を完全には取り除き得ないだろうが，日周成分と半日周成分が卓越していれば上記の方法によって平均的な流況は十分把握できると考えられる．

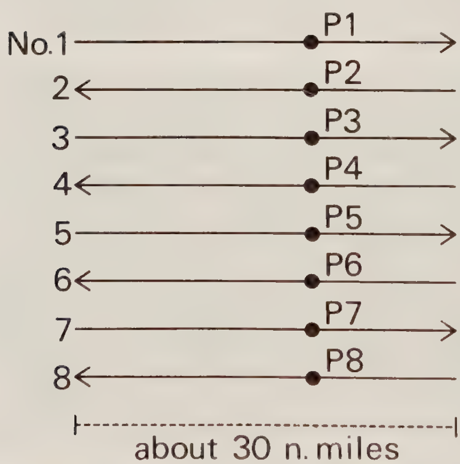


Fig. 2. 24時間50分での4往復調査（地点 P は調査定線上の任意の地点）
Four times plying observation during 24 hours and 50 minutes. No. 1–8 ; observation number. P ; a point arbitrarily set on the observation line.

なお調査海域の緯度（33°55′—34°31′）に対応する慣性周期は21時間11分—21時間30分であるので慣性流は日周潮流に含めて処理した．

2） 測定方法

調査実施方法及び調査時間をそれぞれ Fig. 3，Ta-

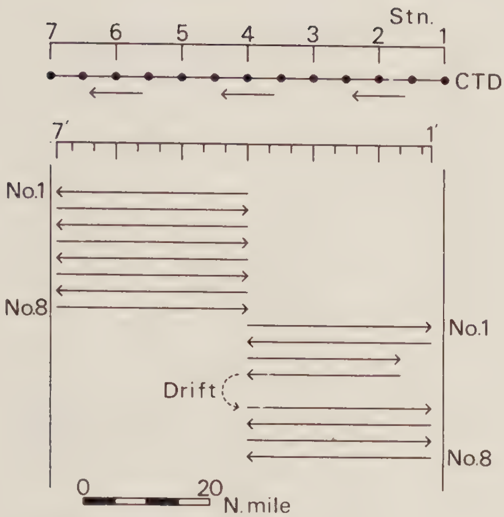


Fig. 3. 流況調査実施方法
Illustration of the current observation.

ble 1 に示す．調査海域での力学計算をするため CTD（アレック電子 AST-1000）による水温，塩分観測を実施した．地点1から地点7に向けて出発し，地点1—7および隣接した地点の中間点で観測を行った．力学計算では海底付近を無流面とした．

地点7から地点4に戻った後，区間4—7′（船速の関係上，地点7を沖合に約1海里移動させて地点7′とした）の往復調査を行った．次に区間1′—4（地点1′は地点1を沖合に約2海里移動した地点）の往復調査を行った．往復調査中はほぼ一定速度（10—11ノット）で航行した．ただし区間1′—4の調査中，濃霧のため3，4回目の調査では一部の区間で欠測となり，また当初の予定を変更して4回目終了後地点4で漂流調査を実施した．

漂流調査は地点4における往復調査から求めた残差流と漂流調査による1昼夜の観測結果を調和分析して求めた残差流とを比較するために実施し，それによって往復調査から求められる残差流の測定精度を検討した．この場合，地点4付近では水深が約100 m あるため，アンカーによる調査船の定位は行わず漂流しながら流れを測定した．この間約4時間毎に一旦地点4に戻り再び漂流した．この約4時間の漂流によって調査船は地点4から3—4海里離れるが，今回の漂流区域内では流れはほぼ一様であると仮定した．

調査期間内での潮高をみるため，潮汐表[6]による博多及び厳原における潮高を Fig. 4 に示す．6月4日—7日の月齢は7.5，8.5，9.5，10.5であり期間内で

Table 1. 調査時間ならびにその実施状況
Time table for the current observation.

Observation		Course	Start time	End time	Lapse
CTD obs.		1→7	June 3, 23：03	June 4, 06：55	7hr 52min
Plying obs.	No. 1	4→7′	June 4, 10：10	June 4, 13：12	3hr 2min
	No. 2	7′→4	13：18	16：04	2hr 46min
	No. 3	4→7′	16：13	19：19	3hr 6min
	No. 4	7′→4	19：27	22：28	3hr 1min
	No. 5	4→7′	22：35	June 5, 01：32	2hr 57min
	No. 6	7′→4	June 5, 01：38	04：39	3hr 1min
	No. 7	4→7′	04：47	07：45	2hr 58min
	No. 8	7′→4	07：51	10：53	3hr 2min
Plying obs.	No. 1	4→1′	June 5, 10：53	June 5, 13：45	2hr 52min
	No. 2	1′→4	13：57	17：02	3hr 5min
	No. 3	4→1b	17：07	19：32	2hr 25min
	No. 4	1b→4	20：54	23：49	2hr 55min
	No. 5	4→1′	June 7, 00：40	June 7, 03：40	3hr
	No. 6	1′→4	03：47	06：48	3hr 1min
	No. 7	4→1′	06：53	09：51	2hr 58min
	No. 8	1′→4	09：59	13：02	3hr 3min
Drift obs.		4	June 5, 23：50	June 7, 00：40	24hr 50min

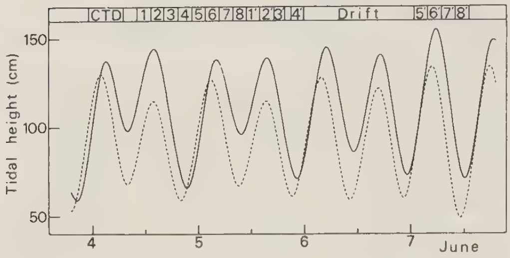


Fig. 4.　調査期間中の博多（——）および厳原（……）の潮高
図の上端に示される1-8は区間4-7′の調査回次を，1′-8′は区間1′-4の調査回次を示す
Tidal heights at Hakata (——) and Izuhara (……) during the observation period. No. 1-8 and No. 1′-8′ (top of Fig.) indicate the observation number of the course 4-7′ and the course 1′-4, respectively.

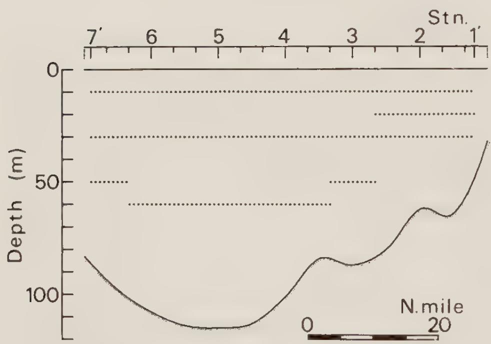


Fig. 5.　往復調査中の流れの観測層
Observation layer during the plying observation.

の潮差は小さい．また厳原での変化は博多に比べ位相が30—60分早いことを除くと，両地点とも非常に類似している．日潮不等は4日，5日に比較的大きいが6日以降小さくなる．

3)　流れの観測および表示

往復調査における観測層を Fig. 5 に示す．CI-30は測定範囲が水深の75%以内（ただし200 mを超えない）であるため，第1層は10 m，第2層は30 mと定め，第3層は水深に応じて20 m，50 m及び60 mのいずれかに選定した．また1′—7′の各地点及び各地点間を3等分する地点をチェックポイントとして調査船が通過した時刻を記録した．区間1′—2，6—7′については区間1—2，6—7の3等分点を用いた．なお各区間を3等分する地点は九州から対馬方向にむかって1a, 1b, 2a, 2b, …とする．流れの観測値としては5分間の移動平均値を採用し，併せて位置，時刻，水温，風向及び風速を5分間隔でプリンターに打ち出した．測定層レンジの変更はチェックポイントを通過した後，初めてプリンターに記録が打ち出された直後に行った．レンジ変更は5—10秒で完了した．漂流調査における観測層は10 m，30 m，60 mとした．

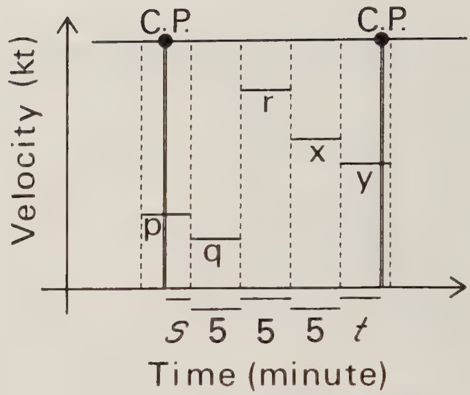


Fig. 6.　チェックポイント間の所要時間および流速
p, q, r, x, y はプリンターに打ちだされた流速を，また *s*, *t* は流速 p, y での所要時間を示す　C. P. はチェックポイントを示す
Required time and current velocity between two check points. p, q, r, x, y ; current velocity printed out on printer. *s*, *t* ; the required time at current velocity, p and y, respectively. C. P. ; check point.

次に隣接したチェックポイント間の区間を1つの単位（単位区間と呼ぶ）とし，次のように各単位区間ごとの代表値を求めた．

5分間隔でプリンターに打ち出された流速（単位ノット，ただし北方成分と東方成分に分ける）の変化が Fig. 6 のような場合を考える．単位区間を通過する間に調査船の下を流れる海水の累積移動距離は次のように考えられる．

$$\mathrm{p}\times\frac{s}{60}+(\mathrm{q}+\mathrm{r}+\mathrm{x})\times\frac{5}{60}+\mathrm{y}\times\frac{t}{60}\ (\text{海里})\cdots\cdots①$$

一方，単位区間を通過するのに要した時間は

$$\frac{s+5+5+5+t}{60}\ (\text{時間})\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots②$$

したがってこの単位区間の流速の代表値は①②より

$$\frac{\mathrm{p}\times s+(\mathrm{q}+\mathrm{r}+\mathrm{x})\times 5+\mathrm{y}\times t}{s+5+5+5+t}\ (\text{ノット})\cdots\cdots\cdots③$$

とした．ただし単位区間内でレンジ変更がある場合，流速 p の s 分間は測定幅が異なるので

$$\frac{(q+r+x)\times 5+y\times t}{5+5+5+t} \quad (ノット) \cdots\cdots\cdots\cdots\cdots 4$$

とした．このようにして求めた代表値を用いて単位区間の中央点における流れを示した．

区間4－7′と区間1′－4の同じ番号の観測には時間のずれがあるが（Table 2），No. 1～4ではほぼ24時間50分のずれで潮流の位相はほぼ同じと考えられる．No. 5～8では約50時間10分（24時間50分×2＋30分）ずれており位相は約30分ずれることになるがここではその差を無視することとし，区間4－7′の結果と区間1′－4の結果を合わせて表示した．

代表値を各単位区間ごとに8回分平均したものを残差流として表示した．なお調査期間中の気象の変化については考慮しなかった．

Table 2. 区間4-7′および区間1′-4の中間点を通過する時刻および時間のずれ（Fig. 3参照）
The passing time at middle point of the observation course 4-7′ and the course 1′-4, and time lag between courses (see Fig. 3).

No.	Course 4-7′	Course 1′-4	Time lag
1	June 4, 11：48	June 5, 12：22	24hr 34min
2	14：39	15：28	24hr 49min
3	17：53	18：33	24hr 40min
4	20：58	21：51	24hr 53min
5	June 5, 00：10	June 7, 02：12	50hr 2min
6	03：05	05：17	50hr 12min
7	06：21	08：26	50hr 5min
8	09：23	11：30	50hr 7min

結　果

1）往復調査

調査断面における調査回次別の流れの分布を Fig. 7 に示す．

(1)～(3)については 1′-2a，2a-6 及び 6－7′の3区域に類別できる．1′-2a では流向は北東－南東で各層とも0.2－0.4ノットが中心となるが上層よりも下層の方が多少大きい．2a-6 では北東－東北東方向を中心とした流れで占められている．10m，30m層では 4b-5 に強流域がありそれぞれ1.1ノット，1.0ノットの流れである．60m層では最大流速は1.0ノットと上2層とほとんど同じであるが強流域は 4a-4b と少し九州側にずれる．6－7′では南西－西南西方向を中心とした流れとなり，7′付近が強流域で10m層で0.7ノット30m層で0.5ノット，50m層で0.3ノットとなる．

(4)では北東－東北東方向の流れが急に弱くなり，南西方向を中心とした流れが 5a から7′まで占める．強流域は7′付近にあり0.9ノットに達する．一方，1b-5a では流れは小さく，4－5の10m層において東南東方向の0.6ノットの流れが最大で30m，60m層では0.3ノット以下の場合が多い．

(5)でもこの傾向が続き 1′-2b では2付近を中心として南南西方向の流れが見られる．また 5a-7′ではこれまで7′にあった強流域が10m層では 6-6a に移動している．

(6)になると再び北東－東北東方向を中心とした流れが優勢となる．2－6では10m，30m層で4－5に強流域があり双方とも1.0ノットの流れである．60m層では九州側に強流域がずれており 3a-3b で0.9ノットとなる．一方，南西方向を中心とした流れは(5)に比べて幾分小さい．1′－2では再び北東－東北東方向に流れる．

(7)ではさらに北東－東北東方向の流れが強くなり，1′から 6a まですべてこの流向になる．しかし 2-2a を境界として2つの区域に分けられ，強流域は 1′-1a と5付近の2ヶ所存在する．1′-1a では10m層で0.7ノットであるが5付近では10m，30m層で1.3ノットを超える流れとなり 60m層でも 0.9ノットである．

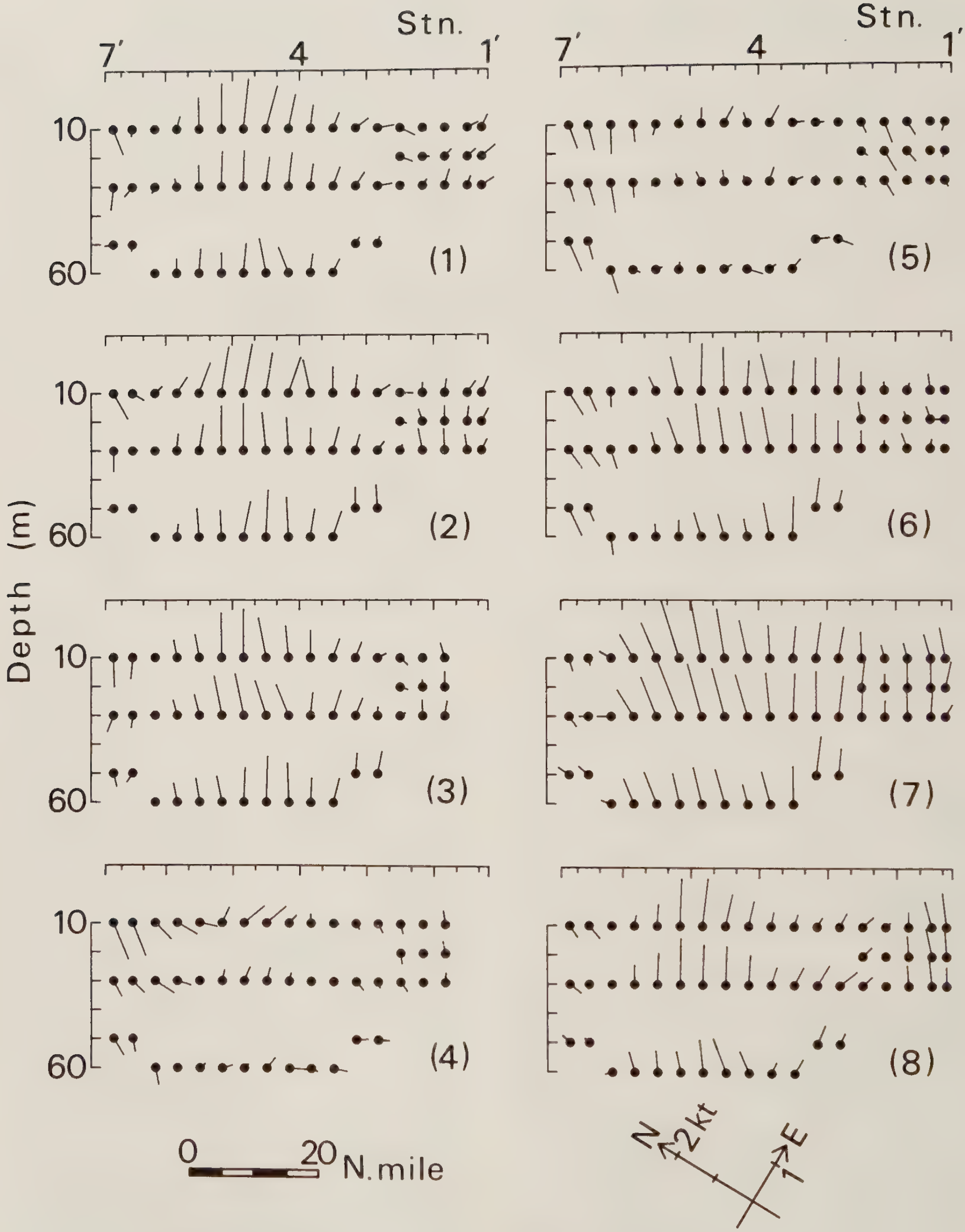


Fig. 7. 調査断面における観測回次別の流れの分布
区間4-7′および区間1′-4における同一観測回次の測流結果を合わせて表示している
Vertical current patterns along the observation line. (1)-(8) corresponds to the observation number 1 8, respectively. The data were combined for the course 4-7′ and the course 1′-4.

6a-7′では南西方向の流れが弱まり50m層では上層と反対方向に流れている.

(8)でも流向が東北東中心と少し東偏するものの全体の傾向は(7)とほとんど同じである. ただし2－6での流れが小さくなっている.

以上のことより(1)～(8)を流れの特徴から2つに分類できる.

1つは北東—東北東方向を中心とした流れが優勢な場合で(1)(2)(3)(6)(7)(8)が相当する. 1′—7′は3区域に分けられ境界は 2-2a と 6-6a にある. 1′—6は全体的に見ると流向は北東—東北東であるが境界 2-2a の九州側は対馬側に比べて流れは小さい. 境界の対馬側では強流域は5付近にあるが60m層では幾分九州側にずれることもある. 一方, 境界 6-6a の対馬側では反流域を形成して南西—西南西方向を中心とした流れとなるが北東—東北東方向の流れに比べると小さい.

もう1つは反流域が 5a まで拡大する場合で(4)(5)に相当する. 南西—西南西方向の流れは(4)(5)以外の場合と比べて大きくなるが 1′-5a では流れは小さく, しかも地点によって流向の変化が大きい. (4)(5)は低潮時から上げ潮時に相当しているが1日2回見られる低潮のうち低い方にのみ相当する (Fig. 4).

2) 残差流の分布

(1)～(8)を平均化したものが今回求めようとした残差流の分布に相当する. Fig. 8によると 2-2a と6付近に境界があり, そこではほとんど無流に近い. 境界 2-2a の両側では流向は各層とも北東—東北東であるが, 九州側の沿岸域では対馬側に比べて流れはかなり小さく0.3—0.4ノットである. 対馬側では10m, 30m層で 4b-5, 60m層で 4a-4b に強流域が存在し, 流速はそれぞれ1.0ノット, 0.8ノット, 0.7ノットとなる. 境界6の対馬側では南西—西南西方向の流れがある. 強流域は各層とも 6b-7′ にあり10m, 30m及び50m層でそれぞれ0.6ノット, 0.4ノット, 0.2ノットとなる.

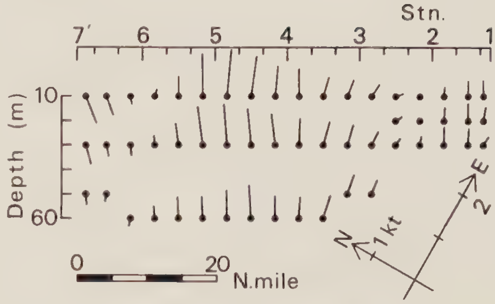


Fig. 8. 往復調査によって求められた調査断面における残差流の分布
Summary of vertical residual current pattern along the observation line, based on the plying observations.

3) 往復調査結果の検討

往復調査結果について漂流調査ならびに力学計算結果との比較を行った. 往復調査による残差流としては地点4をはさむ2つの単位区間の残差流を平均した値を使用した.

Fig. 9, Table 3 によると往復調査と漂流調査との流速の誤差は10m, 30m及び60m層でそれぞれ2.3, 7.9, 9.7%といずれも10%以下である. また流向の誤差は30m層では 2.0° と極めて小さく, 10m, 60m層

Table 3. 地点4における残差流についての往復調査結果と漂流調査結果との比較
Comparison between residual currents obtained from the plying observation and the drift observation at Stn. 4.

Layer (m)	Plying obs.		Drift obs.		Deviation*	
	Vel (kt)	Dir (°)	Vel (kt)	Dir (°)	Vel (%)	Dir (°)
10	0.589	62.5	0.603	52.8	2.3	9.7
30	0.591	56.9	0.642	54.9	7.9	2.0
60	0.445	62.1	0.493	51.5	9.7	10.6

* Deviation is defined by the following formula.

Velocity (%) : $\frac{|\text{value from the plying obs.} - \text{value from the drift obs.}|}{\text{value from the drift obs.}} \times 100$

Direction (°) : |value from the plying obs. – value from the drift obs.|

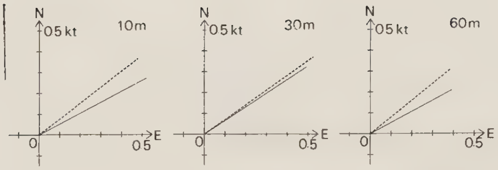


Fig. 9. 地点4における残差流についての往復調査結果（——）と漂流調査結果（……）との比較
Comparison between residual currents obtained from the plying observation (——) and the drift observation (……) at Stn. 4.

でも9.7°，10.6°と10°程度に収まっている．

往復調査及び力学計算から求めた調査断面での流れの分布を Fig. 10 に示す．6—7の南流，1—2及び4—5の北流の分布は両者とも見られ，5付近に強流域が存在する点では一致している．しかし5付近の流れの大きさは力学計算結果と往復調査結果との間で異なっており，また力学計算では2—4の広範囲に南流が見られる点でも往復調査結果と大きく異なる．

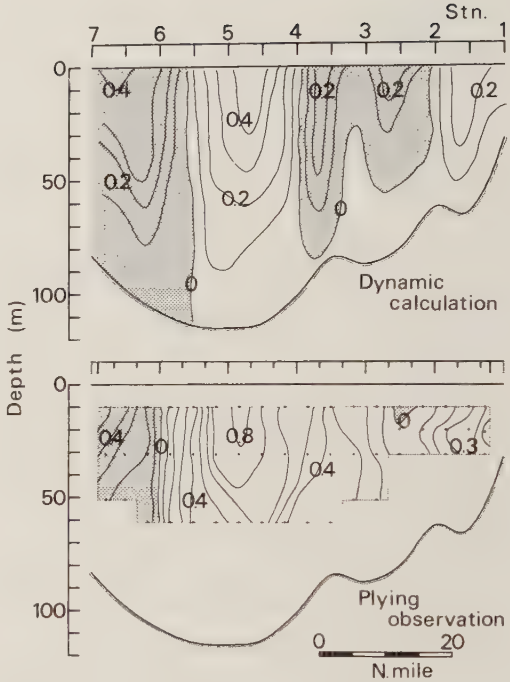


Fig. 10. 力学計算および往復調査のそれぞれから求めた流れの分布（単位；ノット）陰影部は反流（南西流）域を示す
The current pattern obtained from dynamic calculation and the plying observation (unit ; kt). Area shaded shows southwestward counter current.

考　　察

今回の調査断面の大部分では北東—東北東方向の流れで占められており，断面最深部の上層で強流が見られる．また対馬沿岸では南西—西南西方向の流れが各層とも見られ，これまでの報告[7]とよく一致している．しかし福岡県沿岸域においては，南流の存在が多く報告されているが[8,9]本調査では北東—東北東方向の流れであった．三井田[10]によれば福岡県沿岸の南下反流は常時存在するというわけではなく，今回のように北東—東北東方向の流れが存在する場合もかなりあることが考えられる．したがって今回得られた残差流の分布はこれまでの知見とよく対応しており，当海域の流れの特徴を十分表したものであると言えよう (Fig. 11)．

また，往復調査から求めた残差流と漂流調査から求

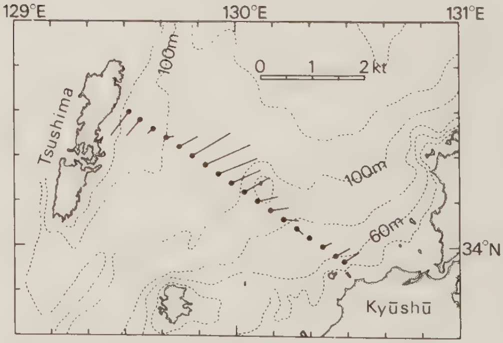


Fig. 11. 調査定線上の10m深における残差流の分布
Distribution of residual current at 10m depth along the observation line.

めた残差流とは，ほぼ同じ値であった．したがって，漂流調査を地点4での係留調査に相当するものとすると，残差流の分布を調べる場合，漂流または係留調査によって一昼夜連続的に流れを観測しなくてもここで述べたような往復調査によって概略的な値は把握できると考えられる．

一方，力学計算から求めた流れの分布は往復調査結果とはかなり異なるものであった．調査結果が示すように対馬東水道での潮流の影響はかなり強く，また無流面と仮定した海底付近でも実際には0.1—0.2ノットの流れが観測されている．[7] このような点からみて1回だけの CTD による観測結果をもとにした力学計算では，水道のように流れの変化が大きい海域での平均的な流況を知ることは難しいと考えられる．

このように本報告で示したような往復調査方法は，広範囲にしかも鉛直的に数層の流れの分布を知ることができ，また測定精度の点でも力学計算と比べてもかなり良いとみられる．したがって，沿岸域の平均的な流れの状況を把握するための調査においては，この方法は有効に適用できると考えられる．

要　約

1987年6月対馬東水道において24時間50分で同一コースを4往復する方法を用いて流況観測を行った結果，次のような知見が得られた．

1)　対馬東水道での残差流の分布

対馬付近に南西—西南西方向の流れが各層とも見られ10m層で0.6ノットとなる．それ以外は北東—東北東方向の流れで占められるが，福岡県沿岸近くには流れがほとんどない水域がある．この水域の沖合側では断面最深部の上層に強流域があり10m層で1.0ノットであるが，沿岸側では小さく0.4ノットとなる．

2)　超音波式潮流計による24時間50分で同一コースを4往復する流況観測方法は，広範囲にわたる海域での平均的な流れの状況を把握する上で有効であると考えられる．

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シャコ *Oratosquilla oratoria* (De Haan) の生物生産過程に関する生態学的研究

山 崎 誠*

The Ecological Study of Mantis Shrimp *Oratosquilla oratoria* (De Haan) with Reference to Its Bio-production Processes

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ABSTRACT

Mantis shrimp, *Oratosquilla oratoria* (De Haan), is a Stomatopod crustacean inhabiting the sandy mud bottom in the coastal waters of Japan, and one of the important species for fisheries at many localities.

Until now, only a few reports deal with the population dynamics or the ecological aspects of mantis shrimp. So, there has been a strong need to elucidate the mode of life of this species for establishing the fishing technique aimed at stock management and for seeking the possibility of culturing and farming.

In this paper, the ecological aspects of adult mantis shrimp such as the growth of gonad and body and the food intake for sustaining their growth and maturation are explained from the bio-production processes. Its life cycle is then clarified from these interrelations.

Samples of mantis shrimp were taken from offshore Okunai in Mutsu Bay, Aomori Prefecture. Samples for the observations of the reproductive cycle, body growth and gut contents were caught bimonthly with the bottom gill nets which were set at eight stations in this area. Samples for the observations of the diurnal activity with feeding were caught with the same nets as mentioned before at a station 400 m from the shore. As another approach to the problem of viability, rearing experiments were performed in aquariums of about 400 *l* capacity with running water systems at a training center of the culturing fisheries of Minami-Kayabe senior high school, Hokkaido Prefecture. In these aquariums, the shrimps were divided into

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three different groups by body length, and were individually measured and weighed monthly. The food supplied during the rearing experiments was chilled fresh euphausiids. Remains and faeces were removed with siphons within periods no longer than four days.

The developmental processes of germ cells in both sexes were categorized by means of histological examination. On this basis, the maturation processes were defind into four stages for ovaries and five for testes. Further, comparing the ratio of individuals having characteristics of maturation to the whole number in the sample and the values of the gonad index (the ratio of the wet weight of gonadal tissues to the body weight), the annual reproductive cycle in the female population of mantis shrimp was broadly classified into the following five different periods: (1) Recovering period (August-September), (2) Developing period (October-November), (3) Pre-maturing period (December-February), (4) Maturing period (March-May), and (5) Spawning period (June-July). Similarly, the cyclical reproductive processes in the male population were divided as follows: (1) Recovering period (July), (2) Developing period (August-September), (3) Pre-maturing period (October-December), (4) Maturing period (January-April), and (5) Sperm ejecting period (May-June).

From the analysis of the polymodal length frequency distributions in natural population and the observation of moulting in the rearing population, the growth in length of adult showed like steps when moulting, which occurred in August to October.

The regression equation of body length showed a retrogressive geometric growth pattern which formulated is as follows:

$$L_{n+1}=0.755L_n+4.743$$

where L_n and L_{n+1} are body length in cm. before and after an ecdysis respectively.

From this equation and the relations of body weight to body length gained monthly measured from reared individuals, the annual changes of shrimp weight showed a large increment after moulting as observed in the change of length. This was a common feature in both sexes, but with females the increase and decrease of body weight with maturing and spawning was pronounced.

The rearing individuals were dissected bimonthly and at various times during moulting and spawning to separate each body components such as integument, muscle, hepatopancreas and ovary. The relation of the dry weight of each body component to body weight was calculated.

The body length at a certain arbitrary month was put in the length-weight relationship above-mentioned and the body weight derived in such a manner was put in the regression equations of each body component and body weight. Thus, the sea-

sonal changes of dry weight of body components were obtained. In the changes of dry weight of integument and muscle, there were no large increment except during moulting of both sexes. There was a big increase in male hepatopancreas after moulting and little until the next one. In females, there was a gradual decrease after the rapid increment of post-moulting and was smallest after spawning. Further, there was a large seasonal change in the dry weight of ovary as observed in the hepatopancreas, suggesting the existence of a close relationship with spawning. The weight increment with moulting was the result mainly of newly formed integument and muscle.

Judging from the diurnal activity and the presence of organisms in guts each season, the diurnal pattern of activity of mantis shrimp can be said to be nocturnal in spring and autumn, day and night in summer and inactive in winter. Mantis shrimp fed on a high proportion of Crustacea, Mollusca and Pisces. The daily amounts of food taken by adult individual reared with euphausiid were smallest at levels of 20 to 70 mg dry weight per day in December to February. Thereafter, an increase in amount continued and reached 270 to 370 mg between August and October. After reaching the maximum value, the amount decreased rapidly to 100 mg in November and December. The seasonal variations of assimilation efficiencies showed little fluctuation and maintained the level at about 90%.

The caloric values of each body component were calculated by multiplying the dry weight of each body component by the caloric value per unit weight. The annual changes of accumulation and consumption of energy were derived from the difference in bimonthly caloric values measured for each body component. In the muscle, there was a large accumulation of energy in September, which reflected moulting. In female hepatopancreas, there was some accumulation of energy immediately before moulting and at about two months after moulting and there was some consumption of energy from April to July, and in September the time after moulting. On the contrary, in male hepatopancreas, there was no marked change until the time before moulting. There was a large accumulation of energy in the integument from September to October in both sexes, which reflected the formation of new integument and its hardening after moulting, although, there was also a large consumption coinciding with moulting in September. In the ovary, there was a remarkable accumulation and consumption from April to June, which coincided with spawning.

The process of individual production may be described using the following equation:

$$Gb+Gg+R=A=C-F$$

(Gb: body growth, Gg: gonad growth, R: metabolic loss, A: assimilation, C: food

intake, F: rejection).

The amounts of energy required for the growth of body and gonad were derived from the differences between the accumulation and consumption of energy of body components mentioned above. The amount of metabolic loss was derived from calculations based on standard metabolism. From the sum of the amounts of body growth, gonad growth and metabolic loss, the energy of assimilation was calculated. Further, the energy of food intake was derived from the energy of assimilation by means of assimilation efficiencies.

In adult shrimps, 190 to 240 kcal per year was ingested, and about 90% of it was assimilated. Most part of the assimilated energy was metabolic loss. The remaining calories (19-26 kcal in female, about 12 kcal in male) were accumulated in each body component for growth, although, 3-5 kcal (about two per cents of ingested energy) was released out of the body as a result of moulting. Furthermore, in females, 7-14 kcal was spent for the growth of ovary, and 85-90% of it was released during reproduction at spawning. Gross growth efficiencies were indicated 9-11% in females and 5-6% in males. Analyzing the interrelation of gonad growth, body growth and food intake, i. e., the series of energy exchange that started at food intake, going through food assimilation and growth of gonad and body, the life cycle of adult mantis shrimp was categorized to four periods as follows: 1) moulting and body growth period (August-November), 2) hibernating period (December-February), 3) gonad growth and maturing period (March-May), and 4) spawning period (June-July).

目　次

I 緒　　言

シャコは，浅海域の砂泥底を生活領域としている口脚目に属する底生の甲殻類で，わが国では北海道から九州にいたる沿岸内湾域に普通にみられ，地域的には漁獲対象種として重要視されている．

各県の農林水産統計からシャコの漁獲量をみると，多くのところで変動が見られ，漁家の経営を不安定なものにする要因の一つとなっている．このことは，資源管理を考慮した適正な漁獲や資源の保護，あるいは種苗放流による資源の増大といういわゆる管理型漁業技術を確立する方向に進む必要性を示しており，そのためにはシャコの生活様式の実態を明らかにし，個体群の成長や補充・減耗といった数量変動の要因を見極めることが求められていると言える．

しかし，これまでのシャコ類の資源動態やその基礎となる生態学的諸知見[1-9]は，このような見方からは必ずしもシャコの生活様式を把握するための体系的な基礎事項を提供するものではなく，特に，個体維持および種族維持に関する種に固有の成長・繁殖およびこれを支えている食物摂取を中軸とする生態学的分野の総括的な解明による本種の生活様式が把握されているとは言い難いのが現状のようである．

そこで著者は，先に示したような観点からシャコ成体の生殖・成長・食物摂取に関する生態学的な事象と，これらの成果にもとづいて食物摂取から生殖腺成長・体成長に至るまでの摂取エネルギーの配分という生物生産過程について究明し，シャコ成体の生活環を明らかにしたいのでここに報告する．

本論を進めるに先立ち，著者がこの研究に入る動機を与えられ，且つ終始御指導と御鞭撻を賜り，本論文の御校閲にも尽力いただいた，北海道大学水産学部の富士昭教授に衷心より感謝の意を表明するものである．また，この論文の取りまとめに際し，御指導と適切なご助言をいただいた北海道大学水産学部の久新健一郎教授と山崎文雄教授に深謝する．研究実施の間に使用材料の採集に協力され，多大の便宜と助力を惜しまれなかった青森市漁業協同組合奥内支所の高森勇司氏，飼育実験遂行に種々の便宜を図られた北海道南茅部高等学校，および青森市水産指導センターの各位に感謝の意を表するものである．さらに，本論文の作成についてご便宜をいただいた西海区水産研究所長　水戸敏博士，浅海開発部長　古賀文洋博士，並びに浅海開発第3研究室長　鬼頭鈞博士の各位に記して感謝の意を表明する．

II 実験材料と方法

1 実験材料

実験に用いたシャコは，青森県陸奥湾奥内地先より採集した．採集地域は Fig. 1 に示すように沿岸線約2㎞と距岸約5㎞に囲まれた範囲で，底質は平均粒径値（Mφ）が1.3から2.3におよぶ砂質で形成されている（Fig. 1–A）．また，この沿岸での等深線はおおむね北から南に向けて陸岸に接近する傾向をとっており，深度勾配は距岸1㎞までは比較的大きいが，これより沖合に向けて水深の増大は緩慢となり水深35ｍを示すのは距岸3㎞ないし4㎞である（Fig. 1–B）．

生殖周期や体成長の観察，胃内容物組成の検討に用いたシャコは，この海域内に設けた8定点（Fig. 1–B）で底刺網（目合7.6㎝）を用いて採集した．また，摂餌に伴う日周期行動の観察は距岸約400ｍの定線（Fig. 1–B）で同規模の刺網を用いた採集個体によって行った．そのため，得られた個体は，そのほとんどが体長12㎝以上という制約があった．採集したシャコの体長は，額板先端から尾節中央部のV字陥入部までの長さとして測定した（Fig. 2）が，この方法では，各体節結節部の伸縮程度により±2％程度の誤差はまぬがれない．体重の測定に際しては体の付着水，特に腹肢から分枝する鰓の付着水に由来する誤差をさけるためにペーパータオルで付着水を除去してから秤量するようにした．

2 方　　法

生殖腺発達の観察に用いた個体は，体長と全湿重量を測定した後に生殖腺を摘出した．摘出した生殖腺は，秤量の後ブアン氏液で固定し通常のパラフィン切

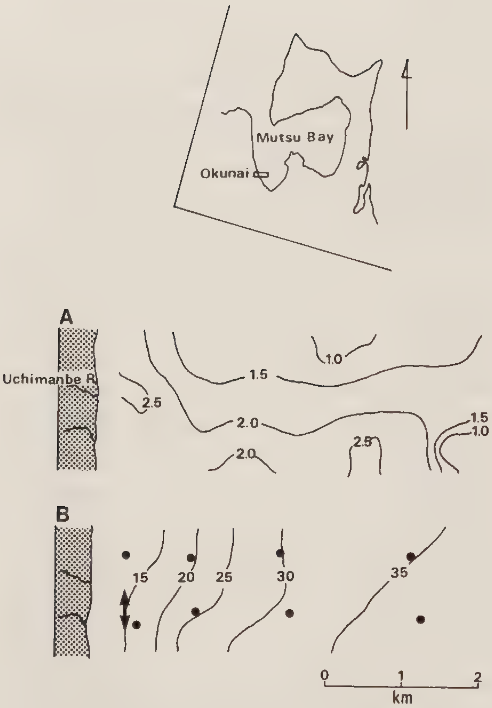


Fig. 1. 陸奥湾奥内沿岸域の底質と地形および採集地点
A：中位粒径値，B：水深（m）と採集地点
Showing sediment characteristics and topography in the coastal water of Okunai in Mutsu Bay.
A : Mϕ contour, B : water depth (m) and sampling stations for monthly (•) and feeding activity (↔).

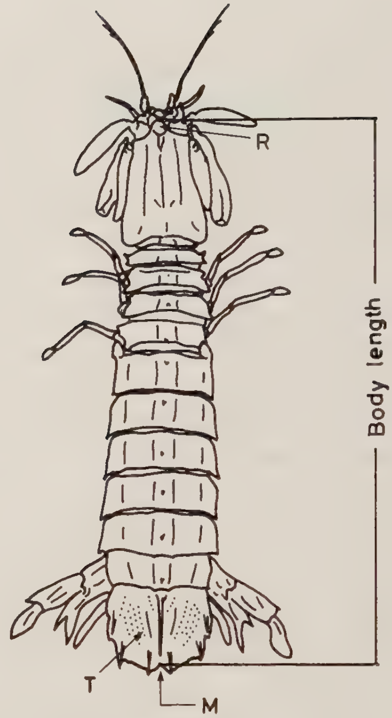


Fig. 2. シャコの体長測定位置
R：額角，M：V字陥入部，T：尾節
Sketch of mantis shrimp showing the positions of the rostrum (R) and the middle incision (M) of the telson (T).

片法により組織標本を作成し，染色・検鏡した．ただし，雄個体では生殖腺組織が極めて軟弱でこれのみを生鮮状態で完全に摘出することは困難であるため，生殖腺の長さを測定した後にその一部を摘出秤量することで全重量を推定するようにした．

室内飼育は，北海道南茅部高校栽培漁業実習場で，約400 *l* 容のパンライト水槽を用いて濾過流水方式を採用して行った．なお，飼育水には常時瀑気を行うことにより酸素供給に努めた．この水槽にほぼ同一体長を有する個体からなる3つの異なる体長群をそれぞれ2群ずつ個別に収容し，そのうち周年観察を行う個体群については第7胸節と第8胸節に着色ナイロン糸を結び付けて個体識別を行い，ほぼ2ケ月ごとに体長・体重の測定を行った．もう一つの群については，飼育個体を2ケ月ごとの定時期と脱皮時および産卵時とに数個体ずつ取り上げて解剖し，外骨格・肉質部・肝膵臓および生殖腺に分離することで各体部位の周年変化の検討に供した．分離・摘出した各体構成部位および脱皮時に回収した脱皮殻・産卵時に採取した卵塊は60℃の恒温下で乾燥し秤量した．なお，外骨格には摘出が困難なために頭胸部に属する胃・眼・第1および第2触角・第2顎脚を除くすべての顎脚，歩脚・腹肢の外肢を含め，また精巣は摘出困難な神経系・血管系とともに肉質部に一括包含した．

飼育実験の期間中，シャコには解凍した生鮮オキアミを充分供給し，水槽底に沈積したオキアミの残渣・シャコの未消化排泄物は，1〜4日ごとにサイフォンで取り除いた．ここで，時間の経過によるオキアミの自己消化の進行を考慮し，シャコを除いた水槽で同一操作を行ってこれに起因する減少率を求め投与量を補

正した.

体構成部位などのカロリー値の測定は，YM燃研式デジタル熱量計を用いて，乾燥・粉砕した試料について行った．また，シャコの酸素消費量は，体重の異なる7〜9個体のシャコを個別に内径3〜5cmのスチロール管に収容し，Winkler 法を用いて測定した流入・流出海水中の溶存酸素量の差をもって算出した.

III 結　果

1 生殖腺の発達

組織学的手法を用いて明らかにされた雌雄生殖細胞の形成過程は，その形態的特徴から山崎・富士[10]により次いように区分されている.

雌の生殖細胞は，成長期・卵黄形成前期・卵黄形成後期・成熟期の4期，雄の生殖細胞は，精原細胞期・精母細胞期・精細胞期・精子期の4期である．さらに，これらの生殖細胞の占める割合をもとに，生殖腺の成熟過程は，卵巣では，回復期・発育期・前成熟期・成熟期の4期に，精巣では，回復期・発育期・前成熟期・成熟期・放精期の5期に区分される.

以上の生殖腺の成熟過程をもとに各成熟過程の生殖腺をもつ個体の採集個体に占める割合から，雌雄個体群の成熟過程は，Fig. 3のようになる．雌個体群では9・10月には回復期と発育期の卵巣をもつ個体が全体の90%以上を占めているが，11月には前成熟期に達した卵巣を持つ個体が80%以上を占めるに至る．この後2月頃までは前成熟期の卵巣をもつ個体が雌個体群の大部分を占める状態を持続するが，2月頃より成熟期に達した卵巣を持つ個体が出現し始め，4月より6月までの期間は90%以上の個体が成熟期の卵巣を保有している．この状態は7月から回復期の個体の急激な出現頻度の増加により変えられ，8月にはほとんどの個体が回復期に相当する卵巣をもつようになる．雄個体群では，9月には回復期と発育期の精巣をもつ個体が全個体の80%を占めているが，10月から急速に前成熟期と成熟期の精巣を持つ個体が出現し，60%から80%の割合を保って3月まで続く．4月および5月には成熟期の精巣をもつ個体だけで60%以上を占めるようになり，この時期から放精期や回復期の精巣をもつ個体が出現し始め，7月にはこれらの個体で雄個体群の60%が占められ，成熟期の精巣をもつ個体は20%以下となる．さらに，7月から8月にかけて，発育期の精巣をもつ個体も急速に増加していく.

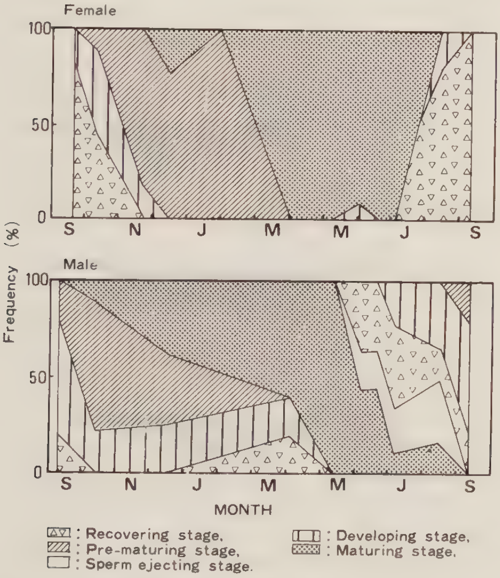


Fig. 3. 雌雄個体群の成熟過程の周年変化
Seasonal changes of the maturation processes of female and male populations.

体重量に対する生殖腺重量の百分率をもってあらわす生殖腺指数（GSI）は，雌個体群では，秋より徐々に増大を続け，5月頃より急激に増大して6月には体重のほぼ14%にあたる最大値に達する．しかし，7月には急激な減少がこれに続いてみられ，9月には最小値になる．雄個体群では，秋に最大値をとり，その後緩慢な減少傾向が春まで続き，翌年の6月に急激な減少を示して最小値をとる．7月には急激に増加し，さらに緩やかな増加を示して秋の最大値へと続く（Fig. 4).

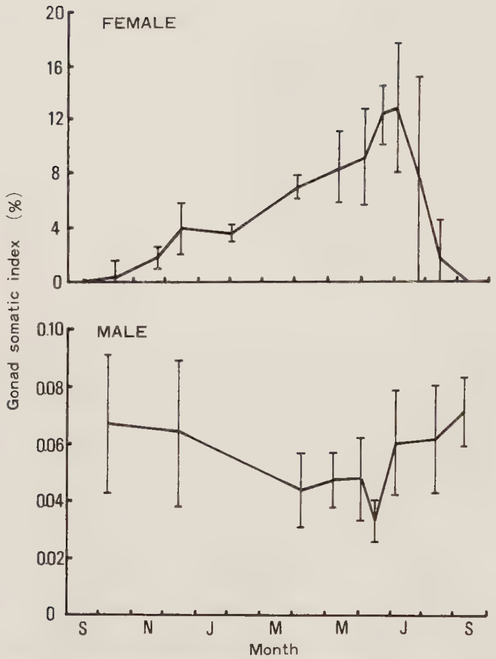


Fig. 4. 雌雄個体群の生殖腺指数の周年変化
Seasonal changes of gonad somatic index of female and male populations. The vertical lines are the standard deviations.

2 体 成 長

1) 体長と体重の周年変化

1976年4月から1977年9月までと，1981年5月から1982年12月までの期間における1ケ月ほぼ1回の定期採集によって得られた個体の体長をもとに，体長測定から得られた多峰性体長頻度分布が正規分布として示されるコホート群の複合した結果であると仮定して，HARDING[11] の確率紙法を用いて内包する正規分布を分離することにより各コホートの平均体長（cm）を求めた．

Fig. 5の同一時期における雌雄個体群の体長頻度分布が示すように，雌雄による体長頻度分布には大きな違いは認められないと仮定して，雌雄を一括した体長頻度分布から分離した正規分布を体長頻度分布とともに示したのが Fig. 6 である．この図から，それぞれの月における多峰性体長頻度分布は1ないし3のコホートを内包すること，破線で示した各コホートの平均体長の変化から，年により多少の違いはあるが，9月から11月にかけて体長の増大が見られることの2点がうかがわれる．

シャコの成長が脱皮によってのみもたらされるかどうかを確かめるために，脱皮をはさんだ数ケ月にわたり個体識別を行った個体の体長の変化を観察した結果が Fig. 7 である．図中の矢印は脱皮した日を示しており，観察個体に関する限り，どの個体も脱皮前の期間および脱皮後の期間における体長は1～3％以内の変動に留まり，それぞれの期間内での有意な体長の変化は認められないのに対して，脱皮をはさむ前後の体長は後者が前者に優っており，有意な違いを示すことがうかがえ，シャコの体長増大が脱皮により非連続的になされることを示している．

さらに，個体識別を行った飼育個体群について，1981年9月から1982年12月までの期間内における脱皮個体数を示したのが Table 1 である．この表から，脱皮は8月から10月の3ケ月に限定されており，しかも雌雄個体により脱皮時期に差異は認められないことが判る．

以上の結果から，Fig. 6に示した各コホートの平均体長を観測時期と対応させて一括して Fig. 8 に示した．シャコの脱皮期間は Table 1 から8月から10月の3ケ月間，体成長が脱皮によってもたらされる非連続型である（Fig. 7）として自然集団の体成長を辿ってみると，各体長群の脱皮期間前後の平均体長は第I群では12.2cmと13.8cm，第II群では14.0cmと15.6cmそ

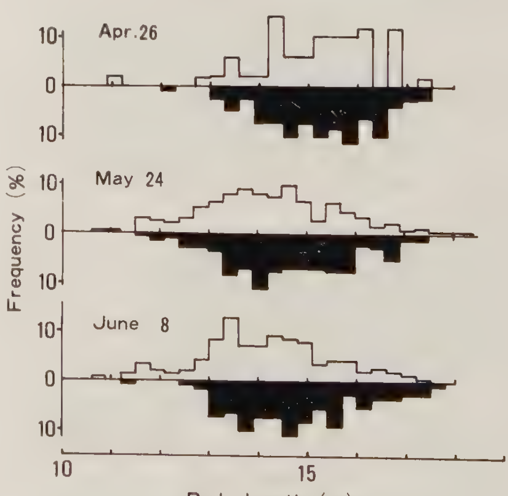


Fig. 5. 採集個体の雌雄別体長頻度分布（白抜きが雌，黒が雄）
Frequency distributions of body length. Upper parts are female and lower parts (black areas) are male.

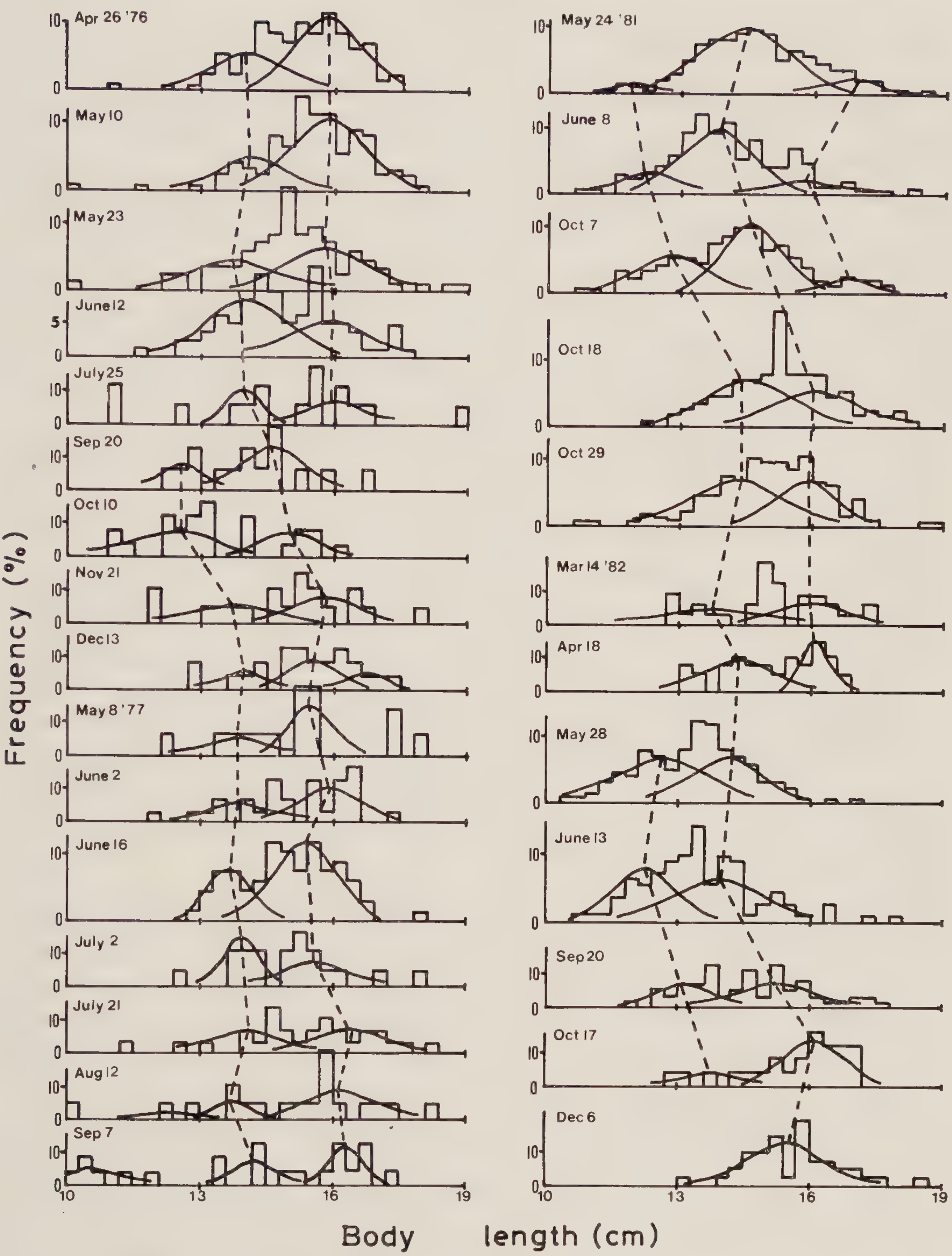


Fig. 6. 体長頻度分布と正規分布曲線（破線は平均値の流れを示す）
Histograms showing the frequencies of body length and several fitted normal curves calculated by the probability graph paper method (Broken lines indicate the flows of the mean length of each cohort).

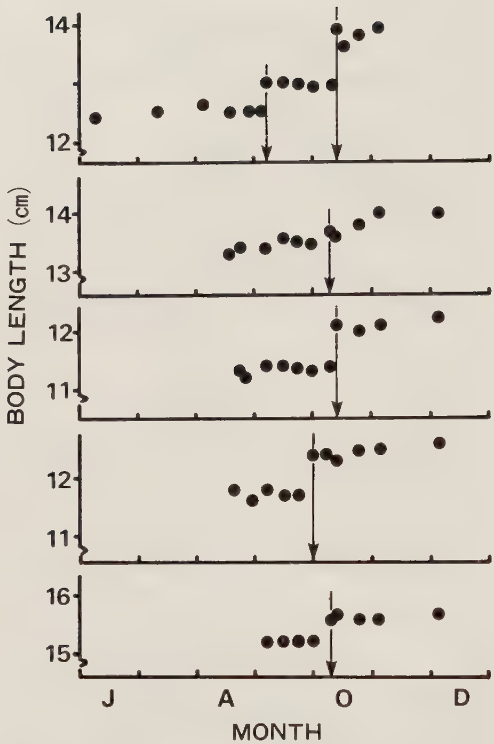


Fig. 7. 飼育個体における脱皮前後の体長の変化
（矢印は脱皮した日を示す）
Changes of body length of mantis shrimp moulted. Arrows indicate the day of moulting.

して第Ⅲ群では15.9cmと16.6cmである．これら3群の値を HIATT[12] の定差図にあてはめて，シャコ成体の体長における成長式を算出すると，

$$L_{n+1}=0.755L_n+4.743 \cdots\cdots\cdots\cdots \quad (1)$$

が得られる．ここでLは体長(cm)を，nは令期を示す．

シャコ体重の周年変化を，1981年11月から1982年12月にわたって月1回測定した飼育個体の体長（L，cm）と体重（W，g）との関係と，先に示した体長の成長式(1)とから各体長群について検討した．その結果，雌雄の月ごとの体長—体重の回帰関係は傾斜に有意な差は認められない（$F=1.02$, $p<0.05$）が，位置には月間に有意差が認められた（$F=6.44$, $p>0.01$）ので，全個体の測定値を一括して算出した傾斜の値と雌雄についての月ごとの測定値から得た体長および体重の平均値とから算出した位置の値（Table 2）により月ごとの回帰式を求めた．また，脱皮直後の個体の体長（Lm）と体重（Wm）および雌個体の産卵直後の体長（Ls）と体重（Ws）の回帰関係は，脱皮直後，産卵前後でそれぞれの回帰関係についての比較を行い，

$$\left.\begin{array}{ll}\text{雌で，} & \log Wm=-1.980+3.068 \log Lm \\ \text{雄で，} & \log Wm=-1.944+3.068 \log Lm \\ \text{また，} & \log Ws\ =-1.960+3.068 \log Ls\end{array}\right\} \cdots \quad (2)$$

という結果を得た．産卵期間は6〜7月（Fig. 4），脱皮期間は8〜10月（Table 1）であるから，産卵・脱皮を便宜的に6月中旬と9月中旬として(2)式により，それ以外の時期については Table 2 によりⅠ，Ⅱ，Ⅲの各体長群の示す体長（Fig. 8と(1)式）に対応する体重を求めたのが Fig. 9 である．体重が脱皮後に大きな増大を示すことでは雌雄個体に共通しているが，雌個体で卵巣の成熟と産卵に伴う体重の増減が顕著である点で雄個体とは大きな違いがある．

2) 体構成部位の成長

各体構成部位の乾燥重量（グラム単位）と体重（グラム単位）との間にはそれぞれ次の式が成立した．

体重（W）と外骨格重量（Ⅰ）：この両者間に成立する回帰関係は，(1)傾斜については月間および雌雄間に有意差は認められないこと，(2)位置の差は雌雄内では

Table 1. 1981年9月から1982年12月の飼育個体においてみられた脱皮個体数
The number of moulting individuals among mantis shrimps reared from September 1981 to December 1982.

	Month															
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Female	2	11	0	0	0	0	0	0	0	0	0	3	6	5	0	0
Male	3	13	0	0	0	0	0	0	0	0	0	3	8	7	0	0
Total	5	24	0	0	0	0	0	0	0	0	0	6	14	12	0	0

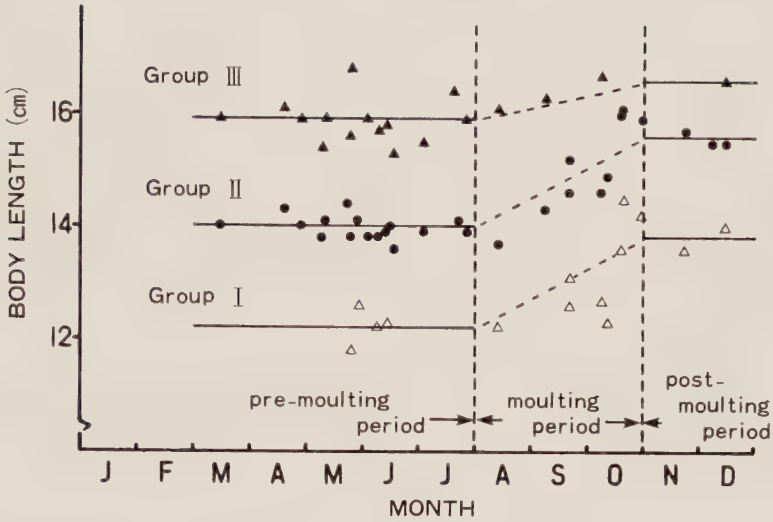


Fig. 8. シャコの体長における周年変化
（各印は Fig. 6 のコホートの平均値の値で，便宜的に大きさ順にグループⅠ，Ⅱ，Ⅲとした）
Seasonal variations in body length of mantis shrimp. Each mark indicates the mean value of each cohort in Fig. 6, and conveniently named Group Ⅰ, Ⅱ, Ⅲ according to size.

Table 2. 飼育個体から求めた体長と体重の回帰関係式 $W=aL^{3.068}$における a の値
Values of constant (a) in length-weight regression equation, $W=aL^{3.068}$

Date	Values of log a	
	Female	Male
Nov., 2	-1.935	-1.925
Dec., 16	-1.946	-1.938
Jan., 5	-1.940	-1.923
Mar., 2	-1.942	-1.917
May, 6	-1.934	-1.924
June, 9	-1.915	-1.933
July, 10	-1.955	-1.938
Aug., 17	-1.951	-1.929
Sep., 6	1.935	1.944
Oct., 5	-1.956	-1.943
Nov., 4	-1.947	-1.944
Dec., 4	1.964	-1.954

月間で非有意であること，(3)しかし，雌雄間では有意であることが認められた（Fig. 10）．これらの事実から，この回帰関係は次式で示すことができる．

$$\left.\begin{array}{l}雌：\log I=-0.850+0.932\log W\\ 雄：\log I=-0.802+0.932\log W\end{array}\right\}\cdots\cdots\cdots\cdots (3)$$

体重（W）と肉質部重量（M）：この両者の回帰関係は Fig. 11 に示すように雌雄間，月間における傾斜の差・位置の差ともに非有意なので，

$$\log M=-1.240+1.107\log W \cdots\cdots\cdots\cdots (4)$$

で一括表示しうる．

体重（W）と肝膵臓重量（H）：この回帰関係は傾斜に雌雄間で有意な差は認められなかったが，位置の差は，雌では月間で有意であるのに対して雄では有意差は認められない（Fig. 12）．両者の間に成立する回帰式は以下のようになる．

$$\left.\begin{array}{l}雌；2月：\log H=-2.688+1.412\log W\\ \quad 4月：\log H=-2.573+1.412\log W\\ \quad 6月：\log H=-2.761+1.412\log W\\ \quad 8月：\log H=-2.860+1.412\log W\\ \quad 9月：\log H=-2.645+1.412\log W\\ \quad 10月：\log H=-2.844+1.412\log W\\ \quad 12月：\log H=-2.526+1.412\log W\end{array}\right\}\cdots (5)$$

$$雄：\log H=-2.663+1.412\log W \cdots\cdots\cdots\cdots (6)$$

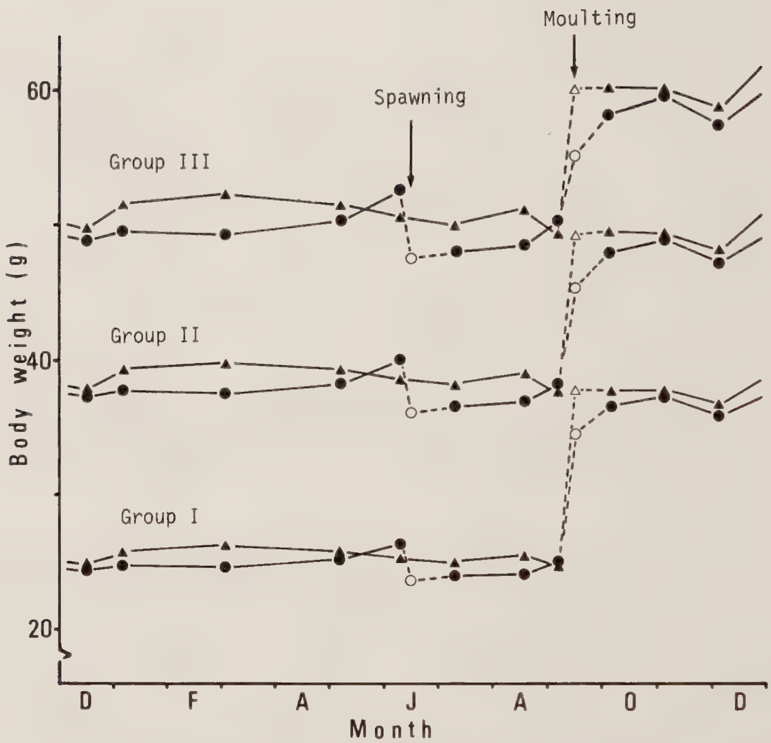


Fig. 9. 体長と体重の回帰関係式および体長の成長式をもとにしたシャコ体重の周年変化（丸印は雌の，三角印は雄の体重を，中抜きの印は産卵・脱皮時の値を示す）
Seasonal changes of body weight calculated from the relation of length-weight regression models. See table 2. Circles indicate the weight of female and triangles indicate that of male.

体重（W）と卵巣重量（G）：両者の対数回帰関係は傾斜の差では月間に有意差は認められないが，位置の差には月間で有意な差が認められ（Fig. 13），次式のような回帰関係が成立する．

$$\left.\begin{array}{l} 2月：\log G=-3.581+1.867\log W \\ 4月：\log G=-3.440+1.867\log W \\ 6月：\log G=-2.706+1.867\log W \\ 8月：\log G=-3.712+1.867\log W \\ 9月：\log G=-4.003+1.867\log W \\ 10月：\log G=-4.261+1.867\log W \\ 12月：\log G=-3.334+1.867\log W \end{array}\right\}\cdots\quad(7)$$

脱皮および産卵直後における体部位重量と個体重：産卵や脱皮は生理的に極めて大きな変化を呈すると考えられるので，特にこの時期の個体重に対する体部位重量の関係を取り上げた．

まず，脱皮直後の雌・雄それぞれの各部位重量と体重の回帰関係と，脱皮前である9月の雌・雄それぞれの各部位重量と体重の回帰関係を比較して，肉質部・肝膵臓・卵巣のそれぞれで傾斜および位置の差に有意な差異がみられず，これらについては9月に成立する回帰式（式(4)，(5)，(6)，(7)）を用い，外骨格についてのみ位置の差に有意な差がみられ，かつ雌雄で有意差がみられなかったので，

$$\log Im=-1.232+0.932\log Wm\cdots\cdots\cdots\quad(8)$$

（Im は，脱皮直後の外骨格の重量，Wm は脱皮直後の体重）の式を用い，さらに脱皮殻と体重の回帰関係は，雌雄で有意な差異が認められず，

$$\log E=-1.252+0.988\log Wm\cdots\cdots\cdots\cdots\quad(9)$$

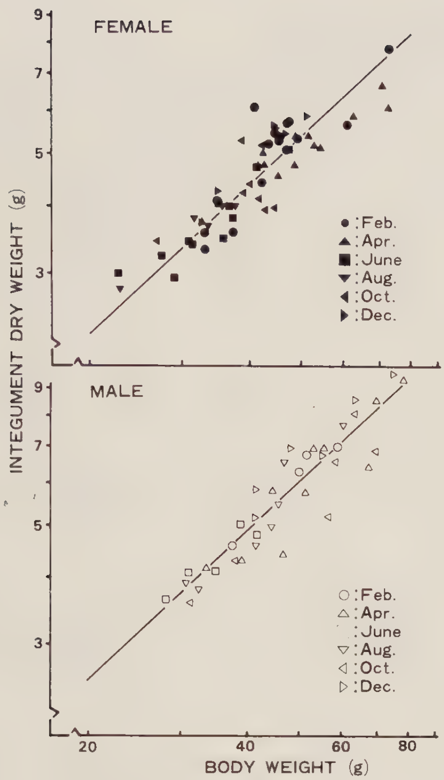


Fig. 10. 体重と外骨格乾燥重量の関係
Relationships between body weight and dry weight of integument of the mantis shrimp reared.

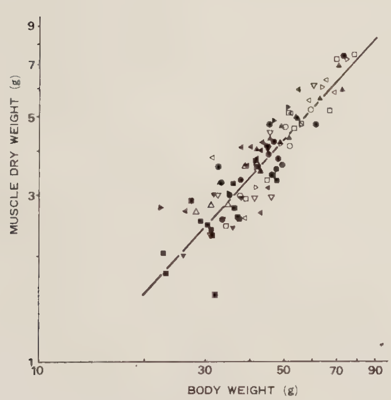


Fig. 11. 体重と肉質部乾燥重量の関係
（各印は Fig. 10 に同じ）
Relationship between body weight and dry weight of muscle of the mantis shrimp reared. The symbols are the same as those used in figure 10.

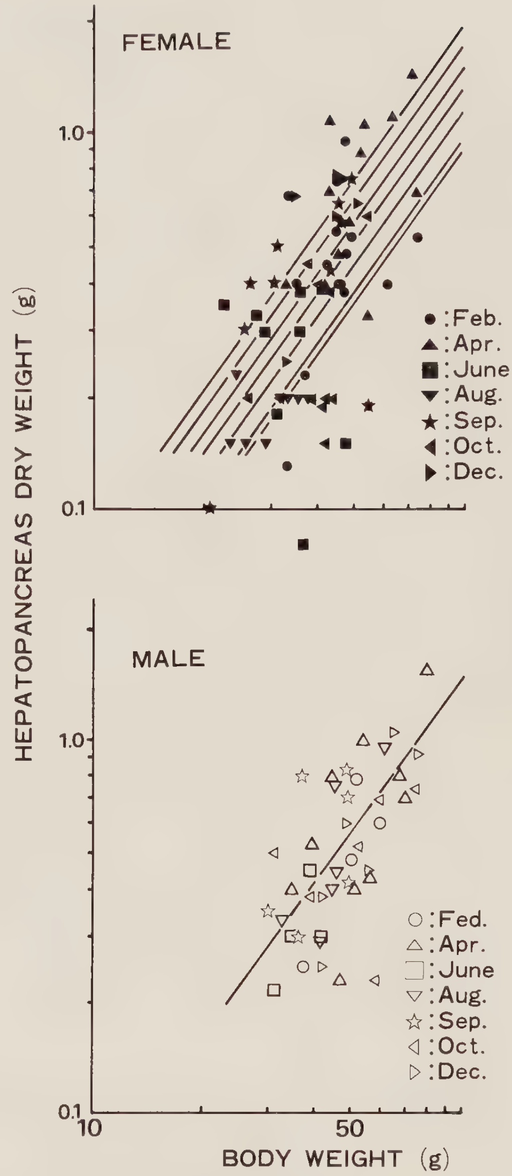


Fig. 12. 体重と肝膵臓乾燥重量の関係
Relationships between body weight and dry weight of hepatopancreas of the mantis shrimp reared.

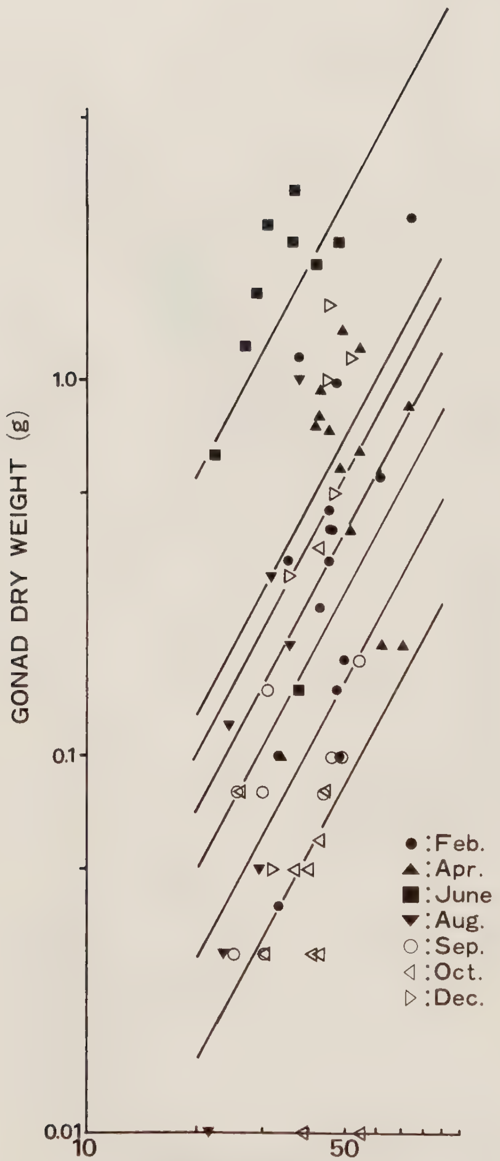


Fig. 13. 体重と卵巣乾燥重量の関係
Relationships between body weight and dry weight of ovary of the mantis shrimp reared.

（Eは，脱皮殻の重量）

なる回帰式が成立した．

次に，産卵直後の雌の各部位重量と体重の回帰関係と，産卵前である6月の雌の各部位重量と体重の回帰関係とから，外骨格・肉質部・肝膵臓のそれぞれで傾斜および位置の差は非有意でありただ卵巣においてのみ位置の差に有意な差異がみられた．それゆえ，産卵直後の雌の各部位重量の算出には6月の雌の各部位重量と体重の回帰式（式(3), (4), (5)）を用い，卵巣のみ次の式を用いた．

$$\log Gs = -3.861 + 1.867 \log Ws \quad \cdots\cdots\cdots \quad (10)$$

（Gsは，産卵直後の卵巣重量，Wsは産卵直後の雌の体重）

シャコは産卵後にその卵塊を保育する[13]ので，産卵量はその卵塊を測定することで容易に把握することができる．飼育期間中に産み出された卵塊と産出雌個体の体重の間には次式が成立する．

$$\log S = -1.387 + 1.039 \log Ws \quad \cdots\cdots\cdots\cdots \quad (12)$$

（Sは，卵塊の乾燥重量）

これまでに得られた体長—体重関係および体重と体部位間にある回帰関係に，任意の月における個体長を代入することにより，その月における個体の体部位重量を推定することが可能となる．体長群I，II，IIIに属する個体の体長の増大に伴う個体重および体部位重量の変化を算出した結果を Table 3 に示した．

体長の増大に伴う個体重および体部位重量は脱皮期を境にして大きな変動を示しており，Table 3 は，(1)脱皮直前まで個体重・肉質部重量は大きな変動を示さないが脱皮後には急激な増大を示し，このことが雌雄の各体長群で共通していること，(2)脱皮による外骨格の損失割合は雌雄とも体長の増大とともに低くなる傾向にあり，新生殻の脱皮前の外骨格に対する重量比も雌雄で体長の増大とともに低くなること，(3)新生殻の重量は急激な増大を示して脱皮後1ケ月でほぼ3倍の重量に達すること，(4)肝膵臓重量は脱皮後から急激な

Table 3. シャコ体構成部位の乾燥重量の周年変化
Changes in dry weight of muscle, hepatopancreas, integument, exuviae, gonad and spawn of mantis shrimp.

Size group	Date	Body length (cm)	Body weight (g) Female	Body weight (g) Male	Dry weight (g) of Female Muscle	Hepat.	Integ.	Exu.	Gonad	Spawn	Male Muscle	Hepat.	Integ.	Exu.
I	Dec., 12	12.2	24.4	24.9	1.98	0.27	2.77	0.00	0.18	0.00	2.02	0.20	3.16	0.00
	Feb., 9	〃	24.7	25.9	2.00	0.19	2.81	0.00	0.10	0.00	2.11	0.22	3.27	0.00
	Apr., 11	〃	24.9	25.8	2.02	0.25	2.83	0.00	0.15	0.00	2.10	0.21	3.26	0.00
	June, 9	〃	26.2	25.1	2.14	0.17	2.96	0.00	0.87	0.00	2.04	0.21	3.18	0.00
	June, 15	〃	23.6	—	1.90	0.15	2.69	0.00	0.05	1.10	—	—	—	—
	Aug., 10	〃	24.1	25.2	1.95	0.12	2.74	0.00	0.07	0.00	2.05	0.21	3.19	0.00
	Sep., 6	〃	25.0	24.5	2.03	0.21	2.84	0.00	0.04	0.00	1.99	0.20	3.11	0.00
	Sep., 15	14.0	34.4	37.4	2.89	0.33	1.59	1.85	0.07	0.00	3.17	0.36	1.71	2.00
	Oct., 13	〃	36.5	37.4	3.09	0.23	4.04	0.00	0.05	0.00	3.17	0.36	4.61	0.00
	Dec., 22	〃	36.8	38.0	3.11	0.48	4.07	0.00	0.39	0.00	3.23	0.37	4.68	0.00
II	Dec., 12	14.0	37.3	38.0	3.16	0.49	4.12	0.00	0.40	0.00	3.23	0.37	4.68	0.00
	Feb., 9	〃	37.6	39.5	3.19	0.34	4.15	0.00	0.23	0.00	3.37	0.39	4.85	0.00
	Apr., 11	〃	37.9	39.3	3.22	0.45	4.18	0.00	0.32	0.00	3.35	0.39	4.83	0.00
	June, 9	〃	39.9	38.3	3.41	0.32	4.39	0.00	1.92	0.00	3.26	0.37	4.72	0.00
	June, 15	〃	36.1	—	3.04	0.27	3.99	0.00	0.11	1.70	—	—	—	—
	Aug., 10	〃	36.7	38.6	3.11	0.22	4.06	0.00	0.16	0.00	3.28	0.38	4.75	0.00
	Sep., 6	〃	38.1	37.4	3.24	0.39	4.20	0.00	0.09	0.00	3.17	0.36	4.61	0.00
	Sep., 15	15.3	45.1	49.0	3.90	0.49	2.04	2.41	0.12	0.00	4.28	0.53	2.20	2.62
	Oct., 13	〃	48.0	49.1	4.18	0.34	5.21	0.00	0.08	0.00	4.29	0.53	5.94	0.00
	Dec., 22	〃	48.3	49.9	4.21	0.71	5.24	0.00	0.65	0.00	4.36	0.54	6.03	0.00
III	Dec., 12	15.3	48.9	49.8	4.27	0.72	5.30	0.00	0.66	0.00	4.35	0.54	6.02	0.00
	Feb., 9	〃	49.3	51.9	4.31	0.50	5.34	0.00	0.38	0.00	4.56	0.57	6.26	0.00
	Apr., 11	〃	49.8	51.6	4.35	0.67	5.39	0.00	0.54	0.00	4.53	0.57	6.23	0.00
	June, 9	〃	52.4	50.3	4.61	0.46	5.65	0.00	3.19	0.00	4.40	0.55	6.08	0.00
	June, 15	〃	47.3	—	4.11	0.40	5.14	0.00	0.18	2.26	—	—	—	—
	Aug., 10	〃	48.2	50.6	4.20	0.33	5.23	0.00	0.27	0.00	4.43	0.55	6.11	0.00
	Sep., 6	〃	50.1	49.0	4.38	0.57	5.42	0.00	0.15	0.00	4.28	0.53	5.93	0.00
	Sep., 15	16.3	54.8	59.6	4.84	0.65	2.45	2.92	0.10	0.00	5.31	0.70	2.65	3.18
	Oct., 13	〃	58.2	59.7	5.17	0.44	6.24	0.00	0.11	0.00	5.32	0.70	7.13	0.00
	Dec., 22	〃	58.7	60.6	5.22	0.94	6.29	0.00	0.93	0.00	5.41	0.71	7.23	0.00

増大を示すが次の脱皮時期まで雄ではほとんど変化が見られないのに対し，雌では漸減傾向を示し生殖物質放出後に示される極小値は極大値のほぼ45%にすぎないこと，の諸点をあらわしている．

体を構成する部位の重量にみられる周年変化の様相は，雌では産卵と脱皮にかかわる物質の蓄積と放出の様相を反映して体の各部位に顕著な変化をもたらしているのに対し，雄では脱皮による体構成部位の増大を除いては周年大きな変化はなく，体長の脱皮による非連続的な段階的増大（Fig. 7 と 8）に並行した型の体部位の増大を示している点で雌個体と異なっていると言える．

3　食 物 摂 取

1)　摂餌活動と食性

1982年6月，9月および12月と1983年3月の各月における任意の1日について薄明時から薄暮時までに2回，薄暮時から翌朝までに2回の連続した各6時間経過ごとのシャコ刺網7把（約350m）に羅網した個体数と，このうち消化管に内容物を保有している個体を示したのが Fig. 14 である．6月の24時間内に羅網した全個体数は37個体で，そのうち24個体は薄暮時から

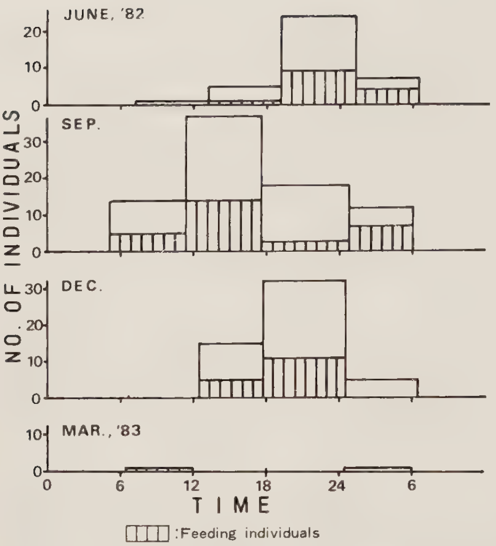


Fig. 14. 薄明時から薄暮時までに2回，薄暮時から翌朝までに2回の連続採集によって得られた個体数の季節変化
Diurnal changes of activity of mantis shrimp.

6時間経過までに羅網した個体である．一方，9月での同様な採集では12時から薄暮時の18時までの6時間に羅網した個体数が全採集個体数（81個体）の46%を占めている．しかも，薄明時から薄暮時までの日中の時間に羅網した個体は夜間を含めた24時間に採集された個体数のほぼ63%に及んでおり，6月のそれの16%に比べてこの月における遊泳活動が日中においても活発であることを推察させている．しかし，この傾向は9月に限定されており，12月には薄暮時から夜半にかけて羅網した個体が過半数（62%）となり，再び6月における活動型と類似した相にもどっている．3月の羅網個体は2個体にすぎず，遊泳活動は周日きわめて不活発であることの反映と考えられる．

これらの採集個体のうち，消化管内容物を有する個体の出現頻度は6月および12月では夜間に羅網した群に高いのに対して9月では周日摂餌個体が見られる．特に夜間よりはむしろ日中において高い点で9月は6月・12月と異なる摂餌活動の相をとっている．

自然個体群の消化管から見出された餌生物の出現状況を，それぞれの餌生物を摂食していた個体の全摂食個体に対する割合としてみたのが Table 4 の結果である．複数種の生物を摂取しているのが普通であるので，餌生物の出現割合の合計は100%を越えた表示にはなるが，どのような生物を餌対象としているかのおおよその傾向は十分知り得る．シャコは，摂取した餌生物を大顎および噴門胃で破砕する[14]が，内容物としての破砕途次の二枚貝の殻板片・魚類の耳石・甲殻類の外骨格が残されているので，これが餌生物としての識別を容易にさせる．しかし，軟体部の破砕・消化は摂餌後急速に進むため，摂食後の比較的短時間内には識別しうるが，それ以外は，種の識別は不可能である．Table 4 中の識別不能欄の個体数はこれによるものである．したがって，胃内容物による食性の判断は硬組織の形で胃内容物として残存している餌生物に偏り，必ずしも食性を正しく反映しないという制約はまぬがれないが，少なくとも胃内容物として識別しえた範囲では，5月から12月までの活動期間には甲殻類，貝類，魚類が高い割合で摂食されていると言える．

Table 4. 各月の摂餌個体数に占める特定餌生物摂食個体数の割合
Proportion of individuals fed certain food organisms to total monthly feeding individuals.

Food organisms	Frequency (%)						
	May	June	July	Sep.	Oct.	Nov.	Dec.
CRUSTACEA	74	47	33	36	50	17	33
PELECYPODA	18	9	24	64	63	83	17
OSTEICHTHYES	21	38	24	55	25	17	17
POLYCHAETA	0	0	10	0	13	0	0
Unidentified	59	31	48	18	0	0	33
Mud & sand	23	7	19	64	25	50	50
Number of total feeding individuals	39	45	21	11	8	6	6

2) 食物摂取量

自然集団の食性で甲殻類が高い割合を占めていることから，ほぼ同一体長を有する個体からなる3群の飼育実験群にたいしてオキアミを餌料として給餌飼育を行うことで，摂餌量および排泄量を測定し，これにもとづいて日間摂餌量および日間同化量を検討した．その結果，体長12cm，14cmおよび16cmの各群の日間摂餌量にみられる季節的変化（Table 5）は群により極大

Table 5. シャコの月平均日間摂餌量と日間同化量および同化効率
Daily amouts of feeding and assimilation efficiencies in each size group of mantis shrimp.

Size group	Month	Daily amount of food eaten (mg dry weight)	Daily amount of faeces excreted (mg dry weight)	Daily amount of food assimilated (mg dry weight)	Assimilation efficiency (%)
I	Dec.	52.15	4.99	47.16	90.4
	Jan.	33.50	11.05	22.45	67.0
	Feb.	69.48	6.51	62.97	90.6
	Mar.	91.60	13.20	78.40	85.6
	Apr.	102.76	6.78	95.98	93.4
	May	139.09	16.38	122.71	88.2
	June	116.08	5.32	110.76	95.4
	July	237.64	10.58	227.06	95.5
	Aug.	269.71	13.05	256.66	95.2
	Sep.	204.86	8.63	196.23	95.8
	Oct.	147.51	13.50	134.01	90.8
	Nov.	134.64	26.58	108.06	80.3
	Dec.	90.19	6.09	84.10	93.3
II	Dec.	57.96	3.42	54.54	94.1
	Jan.	40.12	1.88	38.24	95.3
	Feb.	26.32	0.56	25.76	97.9
	Mar.	120.20	8.55	111.65	92.9
	Apr.	138.06	8.82	129.24	93.6
	May	158.65	14.06	144.59	91.1
	June	197.46	3.09	194.37	98.4
	July	224.15	11.69	212.46	94.8
	Aug.	226.71	7.82	218.89	96.6
	Sep.	214.63	12.98	201.65	94.0
	Oct.	313.72	26.38	287.34	91.6
	Nov.	272.81	21.54	251.27	92.1
	Dec.	88.19	3.15	85.04	96.4
III	Dec.	55.15	2.50	52.65	95.5
	Jan.	25.24	1.70	23.54	93.3
	Feb.	21.06	10.02	11.04	52.4
	Mar.	54.65	9.98	44.67	81.7
	Apr.	128.90	20.34	108.56	84.2
	May	171.11	8.52	162.59	95.0
	June	190.17	10.69	179.48	94.4
	July	232.78	16.94	215.84	92.7
	Aug.	365.99	34.78	331.21	90.5
	Sep.	229.21	16.96	212.25	92.6
	Oct.	176.22	17.87	158.35	89.9
	Nov.	151.00	5.73	145.27	96.2
	Dec.	44.18	3.84	40.34	91.3

値に多少の違いはみられるが，12月から2月にかけて1個体当たり20〜70㎎の水準にあり，その後4〜6月にかけ増加して8月あるいは10月には1個体当たり270〜370㎎に達する．しかし，11・12月には急激に減少してほぼ100㎎以下となる．摂取された食物の同化量は，摂餌量から未消化排泄量を差し引いた値で求め得る．このようにして求めた日間同化量は，Table 5 の第5欄に示された値である．同化量の周年変化は摂餌量のそれと類似した傾向を示しており，体長の異なる群の間で大きな差異はみられない．同化効率は，1・2月に大きな変動をみるが，その他の月では90%ほどの水準にある（Table 5 の最右欄）.

3）食物転換

同化エネルギー量の体構成部位への蓄積と消費の周年変化は，Table 3 に示した各構成部位の重量値の周年変化と各部位の保有する単位重量当りの熱量の周年変化を求めた Table 6 の結果とからそれぞれの月における各体部位の熱量の月間の差として算出することができる．体肉質部・雌雄の肝膵臓・卵巣および未消化排泄物の各カロリー値は，2ケ月ごとの測定値間に有意差が認められなかったので，それぞれの年平均値である 4.43kcal·g dry wt^{-1}，5.56kcal·g dry wt^{-1}，5.23kcal·g dry wt^{-1}，5.09kcal·g dry wt^{-1} を採用した（Table 6）．外骨格のカロリー値については1.63

Table 6. 各体構成部位と排泄物のカロリー値
Caloric values of each body component and faeces.

Month	Caloric values (kcal · g dry wt^{-1})				
	Muscle	Hepatopancreas Female	Hepatopancreas Male	Gonad	Faeces
Feb.	4.58 4.53	6.36 5.84	5.83 5.71	4.80	—
Apr.	4.23 4.47 4.24	5.22 6.35 5.80	4.76 5.99 5.82	5.84	5.00 5.24
June	4.32 4.24	5.09 5.85 5.88	5.43 5.41	5.87 5.46	5.30 5.00
Aug.	4.23 4.40	5.13 5.02	4.86 5.64	5.76 5.16	4.97 4.99
Sep.	4.84 4.51 4.58 4.63	—	—	4.76 4.59	—
Oct.	4.55 4.53 4.11 4.45 4.22 4.32	5.30 5.79 4.75	5.63 5.48	5.19 4.59 5.35	5.00 5.11 4.85
Dec.	4.69 4.36 4.41 4.29 4.68	5.86 5.44 5.81 5.44	5.58 5.67	5.25 5.38	5.22 5.31 5.30
Mean	4.43	5.56		5.23	5.09

±0.15kcal·g dry wt^{-1}，また餌料として与えたオキアミについては 6.05±0.05kcal·g dry wt^{-1}，産卵直後に採取した卵塊については 5.61±0.15kcal·g dry wt^{-1} の値を採用した．

これらの値をもとに，Table 3 に示した月ごとの体構成部位重量を熱量単位として示したのが Table 7 であり，飼育期間における体部位ごとの蓄積エネルギー量を示したのが Table 8 である．肉質部では9月

Table 7. 体構成部位のエネルギー量の周年変化
Changes in each energy value of muscle, hepatopancreas, integument, exuviae, gonad and spawn of mantis shrimp.

Size group	Date	Body length	Body weight (g)		Energy value (kcal) of									
					Female						Male			
		(cm)	Female	Male	Muscle	Hepat.	Integ.	Exu.	Gonad	Spawn	Muscle	Hepat.	Integ.	Exu.
I	Dec., 12	12.2	24.4	24.9	8.77	1.50	4.52	0.00	0.94	0.00	8.95	1.11	5.15	0.00
	Feb., 9	〃	24.7	25.9	8.86	1.06	4.58	0.00	0.52	0.00	9.35	1.22	5.33	0.00
	Apr., 11	〃	24.9	25.8	8.95	1.39	4.61	0.00	0.78	0.00	9.30	1.17	5.31	0.00
	June, 9	〃	26.2	25.1	9.48	0.95	4.82	0.00	4.55	0.00	9.04	1.17	5.18	0.00
	June, 15	〃	23.6	—	8.42	0.83	4.38	0.00	0.26	6.17	—	—	—	—
	Aug., 10	〃	24.1	25.2	8.64	0.67	4.47	0.00	0.37	0.00	9.08	1.17	5.20	0.00
	Sep., 6	〃	25.0	24.5	8.99	1.17	4.63	0.00	0.21	0.00	8.82	1.11	5.07	0.00
	Sep., 15	14.0	34.4	37.4	12.80	1.83	2.59	3.02	0.37	0.00	14.04	2.00	2.79	3.26
	Oct., 13	〃	36.5	37.4	13.69	1.28	6.59	0.00	0.26	0.00	14.04	2.00	7.51	0.00
	Dec., 22	〃	36.8	38.0	13.78	2.67	6.63	0.00	2.04	0.00	14.31	2.06	7.63	0.00
II	Dec., 12	14.0	37.3	38.0	14.00	2.72	6.72	0.00	2.09	0.00	14.31	2.06	7.63	0.00
	Feb., 9	〃	37.6	39.5	14.13	1.89	6.76	0.00	1.20	0.00	14.93	2.17	7.91	0.00
	Apr., 11	〃	37.9	39.3	14.26	2.50	6.81	0.00	1.67	00.0	14.84	2.17	7.87	0.00
	June, 9	〃	39.9	38.3	15.11	1.78	7.16	0.00	10.04	0.00	14.44	2.06	7.69	0.00
	June, 15	〃	36.1	—	13.47	1.50	6.50	0.00	0.58	9.54	—	—	—	—
	Aug., 10	〃	36.7	38.6	13.78	1.22	6.62	0.00	0.84	0.00	14.53	2.11	7.74	0.00
	Sep., 6	〃	38.1	37.4	14.35	2.17	6.85	0.00	0.47	0.00	14.04	2.00	7.51	0.00
	Sep., 15	15.3	45.1	49.0	17.28	2.72	3.33	3.93	0.63	0.00	18.96	2.95	3.59	4.27
	Oct., 13	〃	48.0	49.1	18.52	1.89	8.49	0.00	0.42	0.00	19.00	2.95	9.68	0.00
	Dec., 22	〃	48.3	49.9	18.65	3.95	8.54	0.00	3.40	0.00	19.31	3.00	9.83	0.00
III	Dec., 12	15.3	48.9	49.8	18.92	4.00	8.64	0.00	3.45	0.00	19.27	3.00	9.81	0.00
	Feb., 9	〃	49.3	51.9	19.09	2.78	8.70	0.00	1.99	0.00	20.20	3.17	10.20	0.00
	Apr., 11	〃	49.8	51.6	19.27	3.73	8.79	0.00	2.82	0.00	20.07	3.17	10.15	0.00
	June, 9	〃	52.4	50.3	20.42	2.56	9.21	0.00	16.68	0.00	19.49	3.06	9.91	0.00
	June, 15	〃	47.3	—	18.21	2.22	8.38	0.00	0.94	12.68	—	—	—	—
	Aug., 10	〃	48.2	50.6	18.61	1.83	8.52	0.00	1.41	0.00	19.62	3.06	9.96	0.00
	Sep., 6	〃	50.1	49.0	19.40	3.17	8.83	0.00	0.78	0.00	18.96	2.95	9.67	0.00
	Sep., 15	16.3	54.8	59.6	21.44	3.61	3.99	4.76	0.52	0.00	23.52	3.89	4.32	5.18
	Oct., 13	〃	58.2	59.7	22.90	2.45	10.17	0.00	0.58	0.00	23.57	3.89	11.62	0.00
	Dec., 22	〃	58.7	60.6	23.12	5.23	10.25	0.00	4.86	0.00	23.97	3.95	11.78	0.00

Table 8. エネルギー量でみた各体構成部位における成長量
Amount of absolute growth derived from table 7, expressed in terms of kilocalory.

Size group	Duration of rearing (day)	Amount of absolute growth											
		Female						Male				Total	
		Muscle	Hepat.	Integ.	Exu.	Gonad	Spawn	Muscle	Hepat.	Integ.	Exu.	Female	Male
I	59 (Dec. Feb.)	0.09	-0.44	0.06	0.00	-0.42	0.00	0.40	0.11	0.18	0.00	-0.71	0.69
	61 (Feb. Apr.)	0.09	0.33	0.03	0.00	0.26	0.00	-0.05	-0.05	-0.02	0.00	0.71	-0.12
	59(Apr.-June)	0.53	-0.44	0.21	0.00	3.77	0.00	-0.26	0.00	-0.13	0.00	4.07	-0.39
	6(June-June)	-1.06	-0.12	-0.44	0.00	-4.29	6.17	0.04	0.00	0.02	0.00	0.26	0.06
	56(June-Aug.)	0.22	-0.16	0.09	0.00	0.11	0.00					0.26	
	27(Aug. Sep.)	0.35	0.50	0.16	0.00	-0.16	0.00	-0.26	-0.06	-0.13	0.00	0.85	-0.45
	9(Sep.-Sep.)	3.81	0.66	-2.04	3.02	0.16	0.00	5.22	0.89	-2.28	3.26	5.61	7.09
	28(Sep.-Oct.)	0.89	-0.55	4.00	0.00	-0.11	0.00	0.00	0.00	4.72	0.00	4.23	4.72
	70(Oct.-Dec.)	0.09	1.39	0.04	0.00	1.78	0.00	0.27	0.06	0.12	0.00	3.30	0.45
II	59(Dec.-Feb.)	0.13	-0.83	0.04	0.00	-0.89	0.00	0.62	0.11	0.28	0.00	-1.55	1.01
	61(Feb. Apr.)	0.13	0.61	0.05	0.00	0.47	0.00	-0.09	0.00	-0.04	0.00	1.26	-0.13
	59(Apr. June)	0.85	-0.72	0.35	0.00	8.37	0.00	-0.40	-0.11	-0.18	0.00	8.85	-0.69
	6(June June)	-1.64	-0.28	-0.66	0.00	-9.46	9.54	0.09	0.05	0.05	0.00	-2.50	0.19
	56(June-Aug.)	0.31	-0.28	0.12	0.00	0.26	0.00					0.41	
	27(Aug.-Sep.)	0.57	0.95	0.23	0.00	-0.37	0.00	-0.49	-0.11	-0.23	0.00	1.38	-0.83
	9(Sep.-Sep.)	2.93	0.55	-3.52	3.93	0.16	0.00	4.92	0.95	-3.92	4.27	4.05	6.22
	28(Sep.-Oct.)	1.24	-0.83	5.16	0.00	-0.21	0.00	0.04	0.00	6.09	0.00	5.36	6.13
	70(Oct.-Dec.)	0.13	2.06	0.05	0.00	2.98	0.00	0.31	0.05	0.15	0.00	5.22	0.51
III	59(Dec.-Feb.)	0.17	-1.22	0.06	0.00	-1.46	0.00	0.93	0.17	0.39	0.00	-2.45	1.49
	61(Feb.-Apr.)	0.18	0.95	0.09	0.00	0.83	0.00	-0.13	0.00	-0.05	0.00	2.05	-0.18
	59(Apr.-June)	1.15	-1.17	0.42	0.00	13.86	0.00	-0.58	-0.11	-0.24	0.00	14.26	-0.93
	6(June-June)	-2.21	-0.34	-0.83	0.00	-15.74	12.68	0.13	0.00	0.05	0.00	-6.44	0.18
	56(June-Aug.)	0.40	-0.39	0.14	0.00	0.47	0.00					0.62	
	27(Aug.-Sep.)	0.79	1.34	0.31	0.00	-0.63	0.00	-0.66	-0.11	-0.29	0.00	1.81	-1.06
	9(Sep.-Sep.)	2.04	0.44	-4.84	4.76	-0.26	0.00	3.56	0.94	-5.35	5.18	2.14	4.33
	28(Sep.-Oct.)	1.46	-1.16	6.18	0.00	0.06	0.00	0.05	0.00	7.30	0.00	6.54	7.35
	70(Oct.-Dec.)	0.22	2.78	0.08	0.00	4.28	0.00	0.40	0.06	0.16	0.00	7.36	0.62

に最も大きなエネルギーの蓄積がみられ，脱皮に対応したものであることを示している．ただし，雌では脱皮の前後に著しい蓄積がみられるのに対して雄では脱皮直前に限られており，雌雄での違いがある．肝膵臓でも，雌では脱皮直前と脱皮後2ケ月余りを経た時点にエネルギー蓄積がみられ，消費は4月から7月と9月の脱皮後に対応した時期にみられるのが特徴的で，周年大きな変化を示す．これに対して，雄では著しいエネルギー蓄積が脱皮直前にみられるほかは周年大きな変化を示さず，雌雄で様相を異にしている．外骨格

へのエネルギー蓄積量は9月から10月にかけ最も大きいことが雌雄で共通しており，脱皮後の新しい外骨格の形成増大と硬化に対応している．また，外骨格からのエネルギー消費は9月の脱皮と対応した時期に顕著である．雌の生殖腺では4月から6月にかけてエネルギーの蓄積と放出が顕著で，産卵に対応したものであることをうかがわせる．

同化エネルギーは，最終代謝生産物の排出による消費のほかに，代謝過程における脱アミノ化の過程で利用されなかったエネルギーや食物物質の消化・移送・異化に要するエネルギー，基礎代謝や活動代謝エネルギーとして消費され，その残余が前項で示された体構成物質のエネルギーとして蓄積される．このうち，脱アミノ化の過程や食物物質の消化・移送・異化に要するエネルギーは，Specific dynamic action（特異動的作用）として基礎代謝や活動代謝が示す呼吸量の特別な増量とされている．ここでは，このうちの標準代謝を求め，これを基準として特異動的作用を含めた活動代謝を推定する方法をとった．

酸素消費量の測定は，1月，3月，9月，11月にその時期の飼育水温である9.0℃，11.5℃，19.2℃，15.0℃のもとで行った．なお，4時間ごとに6回の測定を行ったが，時刻による酸素消費量に有意な違いは認められなかったので，その平均をもって体重に対する単位時間当りの酸素消費量として示した．得られた結果が Fig. 15 である．体重に対する単位時間当りの酸素消費量の回帰関係は，水温間で傾斜に有意差は認められない（$F=5.05$, $p<0.05$）ので傾斜については各月を一括し，水温と体重の関数として表現すると次式が得られる．

$$\log R=\log(0.0523\,t-0.0415)+0.2881\log W$$

なお，ここで t は水温（℃），Wは個体の湿重量（g），Rは酸素消費量（$ml\text{-}O_2\cdot h^{-1}$）である．

得られた関係式に，Table 3 に示したシャコの個体重および月々の平均飼育水温（Fig. 16）を代入することで各月におけるその個体の1時間当りの酸素消費量が算出できる．この酸素消費量に 4.83cal/$ml\text{-}O_2$ の酸素カロリー当量[15] を乗ずることで，標準代謝エネルギー量とした．さらに，特異動的作用や平常代謝の合計量を標準代謝量の2倍と見積り，その値を Table 9 第3欄に示した．

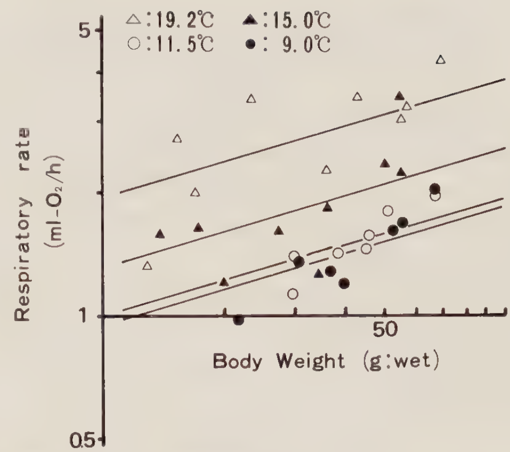


Fig. 15. シャコの酸素消費量の変化
Logarithmic plots of respiratory rate against body weight.

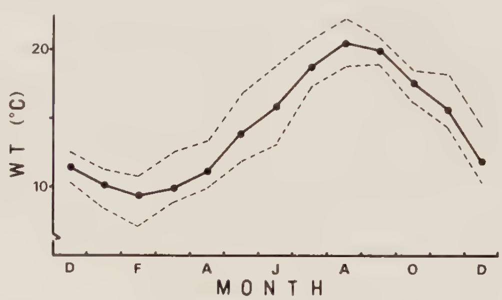


Fig. 16. 飼育水温の周年変化（破線は最低・最高を示す）
Average water temperature in aquaria. Broken lines indicate the range of temperature.

摂取量をC，未消化排泄量をF，代謝排出量をU，同化量をA，体成長量を Gb，生殖腺成長量を Gg，代謝損失量をRとすると，個体の生産過程は，

$$C-F=A=(Gb+Gg)+R+U$$

としてあらわされる．しかし，UはFと厳密には分離しがたい種が多く，量的にも少ないことから，両者を合算して排出量（rejection）としている場合が多い．ここでもこの表現をとることにすると，上式は，

$$C-F=A=(Gb+Gg)+R$$

Table 9. シャコの食物摂取エネルギー量の分布
Food energy distribution in mantis shrimp, each figure is expressed in terms of kilocalory. See text for each abbreviation.

Group	Duration of rearing (day)	Metabolic loss (R)		Growth (G)		Assimilation (A)		Food intake (C)		Rejection (F)	
		Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
	59 (Dec.-Feb.)	17.40	17.56	-0.71	0.69	16.69	18.25	20.45	22.37	3.76	4.12
	61 (Feb.-Apr.)	17.10	17.30	0.71	-0.12	17.81	17.18	19.70	19.00	1.89	1.82
	59 (Apr.-June)	22.78	22.78	4.07	-0.39	26.85	22.39	29.06	24.23	2.21	1.84
	6 (June-June)	2.78	33.10	0.26	0.06	3.04	33.16	34.48	34.51	1.34	1.35
I	56 (June-Aug.)	29.84		0.26		30.10					
	27 (Aug.-Sep.)	16.22	16.30	0.85	-0.45	17.07	15.85	17.76	16.49	0.69	0.64
	9 (Sep.-Sep.)	5.58	5.64	5.61	7.09	11.19	12.73	11.60	13.19	0.41	0.46
	28 (Sep.-Oct.)	17.18	17.40	4.23	4.72	21.41	22.12	22.63	23.38	1.22	1.26
	70 (Oct.-Dec.)	34.04	34.30	3.30	0.45	37.34	34.75	41.91	39.11	4.57	4.36
	59 (Dec.-Feb.)	19.66	19.86	-1.55	1.01	18.11	20.87	18.86	21.74	0.75	0.87
	61 (Feb.-Apr.)	19.30	19.52	1.26	-0.13	20.56	19.39	21.55	20.32	0.99	0.93
	59 (Apr.-June)	25.74	25.72	8.85	-0.69	34.59	25.03	36.76	26.60	2.17	1.57
	6 (June-June)	3.14	37.38	-2.50	0.19	0.64	37.57	35.86	38.77	1.11	1.20
II	56 (June-Aug.)	33.70		0.41		34.11					
	27 (Aug.-Sep.)	18.32	18.42	1.38	-0.83	19.70	17.59	20.39	18.21	0.69	0.62
	9 (Sep.-Sep.)	6.14	6.22	4.05	6.22	10.19	12.44	10.73	13.09	0.54	0.65
	28 (Sep.-Oct.)	18.60	18.88	5.36	6.13	23.96	25.01	25.49	26.61	1.53	1.60
	70 (Oct.-Dec.)	36.82	37.10	5.22	0.51	42.04	37.61	44.53	39.84	2.49	2.23
	59 (Dec.-Feb.)	21.24	21.46	-2.45	1.49	18.79	22.95	20.95	25.59	2.16	2.64
	61 (Feb.-Apr.)	20.88	21.12	2.05	-0.18	22.93	20.94	29.66	27.09	6.73	6.15
	59 (Apr.-June)	27.86	27.80	14.26	-0.93	42.12	26.87	45.39	32.19	3.27	5.32
	6 (June-June)	3.40	40.42	-6.44	0.18	-3.04	40.60	36.13	43.15	2.13	2.55
III	56 (June-Aug.)	36.42		0.62		37.04					
	27 (Aug.-Sep.)	19.82	19.90	1.81	-1.06	21.63	18.84	23.41	20.39	1.78	1.55
	9 (Sep.-Sep.)	6.58	6.64	2.14	4.33	8.72	10.97	9.30	11.70	0.58	0.73
	28 (Sep.-Oct.)	19.68	19.96	6.54	7.35	26.22	27.31	28.28	29.46	2.06	2.15
	70 (Oct.-Dec.)	38.94	39.26	7.36	0.62	46.30	39.88	49.20	42.38	2.90	2.50

となり，同化エネルギー量は代謝エネルギー量と体および生殖腺増生におけるエネルギー量の合算として求めることができる．Table 9 の第3欄と第4欄との合計値がこれで，第5欄に示すような量が同化エネルギー量となる．

Table 5 に示した重量単位で求めた日間摂餌量および日間排泄量を Table 6 に示した排泄物のカロリー当量およびオキアミのカロリー当量（6.05kcal·g^{-1}）により熱量表示とし，これから熱量単位による同化効率を求めると Table 10 のようになる．

Table 10. カロリー量単位をもとに求めた同化効率
Assimilation efficiencies of each size group derived from table 5 and table 6.

Month	Assimilation efficiency (%) Size group		
	I	II	III
Dec.	91.9	95.0	96.2
Jan.	72.2	96.0	94.4
Feb.	92.1	98.2	60.0
Mar.	87.9	94.0	84.6
Apr.	94.4	94.6	86.7
May	90.1	92.5	95.8
June	96.1	98.7	95.3
July	96.2	95.6	93.9
Aug.	96.0	97.1	92.0
Sep.	96.5	95.0	93.8
Oct.	92.3	92.9	91.5
Nov.	83.4	93.4	96.8
Dec.	94.3	97.0	92.7

個体の生産過程では，一般的に

C＝A/同化効率

としてCが求められるので，飼育実験から得られた同化効率と Table 9 に示した同化エネルギー量から，摂取エネルギー量を求め，得られた摂取エネルギー量から同化エネルギー量を差し引くことにより排泄エネルギー量を推定した．これらの一連の値をまとめたのが Table 9 第6・7欄である．

Table 8 と Table 9 はエネルギーの消費と蓄積，同化と排泄をおおむね2ケ月間を単位としたエネルギー収支の周年変化の様相として明らかにしたものである．ここでは，各体長群に属する個体の年間のエネルギー収支をまとめることとした．Table 11 がその結果であり，これにもとづいて餌料（オキアミ）の摂取からシャコ個体を通るエネルギーの流れを，流れの順序に従って示したのが Fig. 17 である．これらの結果から明らかなように，成体個体では年間190〜240 kcal を摂取してそのほぼ90%が同化され，同化エネルギーの大きな部分は呼吸として失われ，残余のエネルギーとして雌での 19〜26kcal，雄での約 12kcal が体を構成する各部位に蓄積されて成長という形をとる．このうち，脱皮によって雌雄とも 3〜5kcal，約2%が体外へ放出され，また雌では，7〜14kcal が生殖腺の成長にあてられるが，産卵によってその85〜90%が生殖物質として体外に失われる．シャコ成体個体では年間の同化効率は90〜95%，摂取したエネルギーが新しい組織に転換される割合（粗成長効率）は雌で9〜11%，雄で5〜6%である．

Table 11. シャコの年間のエネルギー収支
Energy budget in mantis shrimp, *Oratosquilla oratoria* (De Haan). C＝F＋A, A＝R＋G.

Items (kcal/year)	Group I		Group II		Group III	
	Female	Male	Female	Male	Female	Male
Food intake (C)	197.59	192.28	214.17	205.18	242.32	231.95
Rejection (F)	16.09	15.85	10.27	9.67	21.61	23.59
Assimilation (A)	181.50	176.43	203.90	195.51	220.71	208.36
Metabolic loss (R)	162.92	164.38	181.42	183.10	194.82	196.56
Growth: Total (G)	18.58	12.05	22.48	12.41	25.89	11.80
Muscle	5.01	5.36	4.65	5.00	4.20	3.70
Hepatopancreas	1.17	0.95	1.23	0.94	1.23	0.95
Integument	2.11	2.48	1.82	2.20	1.61	1.97
Exuviae	3.02	3.26	3.93	4.27	4.76	5.18
Gonad	1.10	—	1.31	—	1.41	—
Gametes ejected	6.17	—	9.54	—	12.68	—

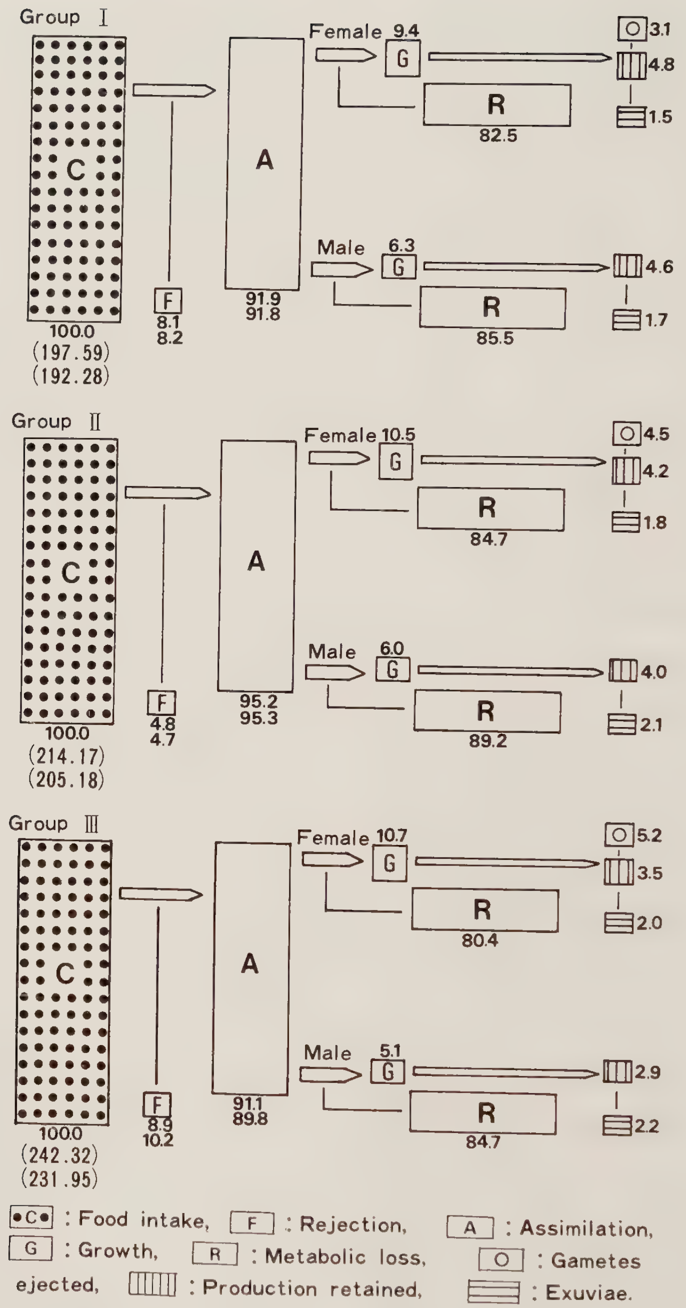


Fig. 17. 摂取から成長に至るエネルギーの転移割合
（食物摂取量（括弧）を100とした）
Scheme showing the rate of energy transformation. The number in each column indicates the rate of energy transformation, expressed as percentage. The number in each parenthesis is the amount of food intake (kcal/year).

Ⅳ 考　　察

個体レベルでの生物物質の生産は，発育・成長という個体維持の側面と繁殖という種族維持に関連する側面とこれを支える種固有のエネルギー転換様式という機能的な側面が統一的に実現された結果であり，その生産過程は個体の示す生活環としてあらわされる．したがって，生産に関連するこれらの各項を明らかにすることは生活環を具体的に認識する際には不可欠の条件となる．

シャコ類の生殖腺の発達については，卵巣重量の変化[1,16]や卵巣重量と体重量の相対比として表した生殖腺指数の変化による成熟過程の推定[8,17,18]，あるいは第6～8胸節腹板にあるセメント腺の白色色彩の濃淡と卵巣の色彩変化[2]より生殖腺の成熟過程を明らかにする試みがなされてきた．しかし，これらの研究は，主として産卵期推定に焦点を合わせているので，周年にわたる生殖腺の成熟過程として把握するためには極めて断片的であり不充分さが残されていた．生殖腺の発達過程の把握には卵および精子形成過程の検討が必要となるが，このような研究は極めて乏しく，わずかにシャコの精子形成過程についての Komai[19] による細胞学的研究がみられるにすぎない．ここでは，雌雄生殖細胞の形成過程を基礎として周年にわたる生殖腺の成熟過程を把握し，個体群のなかでそれぞれの成熟過程にある個体の占める割合の季節変化（Fig. 3）とこれにともなう生殖腺重量の季節的変化（Fig. 4）とから，シャコの生殖周期を Fig. 18 に示すような年周期として把握することができる．すなわち，雌個体群では，回復期：8～9月，発育期：10～11月，前成熟期：12～2月，成熟期：3～5月，産卵期：6～7月，雄個体群では，回復期：7月，発育期：8～9月，前成熟期：10～12月，成熟期：1～4月，放精期：5～6月である．

シャコの資源管理や増養殖を行う上で重要な事項の一つに産卵期の推定があげられる．これまでシャコの産卵期については，石狩湾で6月[16]，東京湾で5月中旬～7月上旬[1]，5月～8月[17]，大阪湾で5月中旬～9月上旬[8]，瀬戸内海岡山県東岸で5月中旬～8月下旬[18,20]と報告されている．そのうち林と辻野[8]は，大阪湾と東京湾のシャコ漁場における底層水温と産卵期間の対比を行うことで，産卵は水温13℃前後で開始され水温下降初期に終了すると指摘している．陸奥湾における底層水温の周年変化と先に明らかにした産卵

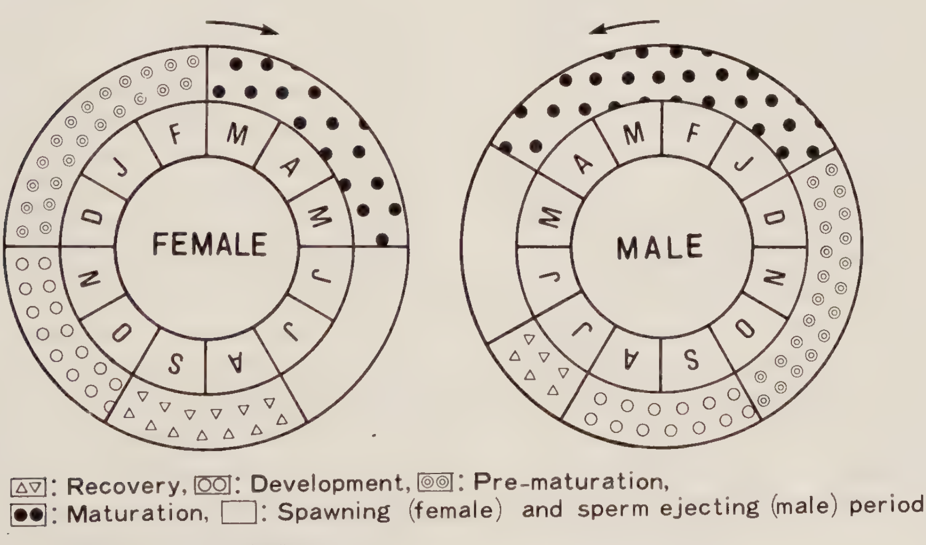


Fig. 18. シャコの生殖周期
Scheme of the reproductive cycles of mantis shrimp.

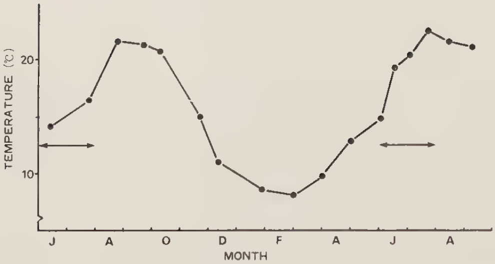


Fig. 19. 陸奥湾奥内地先底層水の水温変化（矢線は産卵期間を示す）
Changes in bottom water temperature during June 1976 to September 1977. Arrow lines indicate the spawning period of mantis shrimp.

時期を対比する（Fig. 19）と，陸奥湾におけるシャコの産卵は，水温15℃付近で開始されると思われる．また，石狩湾，陸奥湾，東京湾の産卵期を比較すると，北方水域ほど産卵開始が遅れ，かつ，産卵期間が短いことが推察できる．

節足動物の発育・成長は，外骨格を形成している古いクチクラが脱ぎ捨てられ，その下にあらかじめ用意されていた表皮と新しいクチクラが硬化することでもたらされる．このような外骨格の周期的な置き換えは物質代謝や再生産，行動などと相互に関連しあい，生活の 諸側面に 大きな 影響を 及ぼしていると考えられる．シャコ類の成長については，REAKA[6,7,21,23] による熱帯・亜熱帯域のサンゴ礁に生息する口脚目数種の個体群にみられる脱皮間期・平均脱皮回数および脱皮による成長量などについての報告がある．しかし，温帯域に生息するシャコ類の成長については，体長組成の頻度分布に基づく体長と推定年齢とから成長式を見積もった報告[1,3,8,17] があるに すぎず， これらの諸報告では脱皮と成長量の関連については触れられていない．また，体重の変化に関しては産卵や脱皮による変化は勿論のこと，体成長に伴う変化の様相についてもこれまでに報告が見られない．さらに，物質代謝や再生産の季節的な変化と直接結びついた形での生物生産過程を把握するためには，体長・体重の増大によって示される体成長を，それを裏づける外骨格や肉質部・肝膵臓・生殖腺といった各体構成部位の重量の季節的な増減として把握することが不可欠である．

シャコの体成長に関して，倉田[23] は，HIATT の成長式によって示される成長係数の値によって，甲殻類の成長を 1）進行性等比成長， 2）退行性等比成長，および 3）等差成長の 3型に大別し， 多くの種では成体で 退行性 等比成長型を とると 結論づけている．シャコ類の 脱皮と 体長に みられる 体成長について，REAKA[7] は，亜熱帯域に生息する *Gonodactylus chiragra* と *G. viridis* の成体では体長による脱皮間日数に差異はないこと，成長量も *Gonodactylus* 属のほとんどの種で指数関数型を示し百分成長増加率が体長の増大に伴い減少するのは *G. chiragra* など数種に限られると報告している．本研究で明らかにした，シャコ成体の体成長式(1)は 成長係数が 0.755であることを示し，倉田[23] の退行性 等比成長に該当する． シャコの体重にみられる成長の変化についても，Fig. 9 から明らかなように体長と同様脱皮を契機として大きな変化を示す．これまで，甲殻類の体重についてはその多くが体長との回帰式を求めるにとどまってきた[24,27]．このことは シャコでも 例外ではなかった[1,3,8] ために体重の季節変化や脱皮前後の個体重変化は把握されることがなかった．わずかに脱皮前後の体重の変化が吸水に起因する 増重であること[28,29] が知られて いるにすぎない．Table 3 で明らかにしたシャコ成体における体重・体を構成する各部位の重量変化として把握した成長の様相は，甲殻類特有の脱皮現象に伴う重量の増大が主として新生殻と体肉質部の増重によることを指示しており，脱皮を契機とする体重変化の内容を明らかにし得たことは生活環究明の上から有力な知見を得たものと考えられる．

先に示した結果から明らかなように，シャコ成体の生殖腺成長の様相は，産卵前にみせる急激な増加を特徴としており（Fig. 4 および Table 3），さらに，雌に特異的にみられる肝膵臓の 4月から 8月までの減少傾向（Table 3）を伴って，産卵を完結させている．生殖腺指数にみられるこの急激な増加は，他の海域のシャコでも共通な現象としてうかがえる[8,17,18]．

甲殻類の肝膵臓は，グリコーゲン・脂肪・カルシウムの貯蔵器官とされ[31,32]，脂肪やグリコーゲンの容量が生殖細胞の形成過程と関連して季節的に変化するともいわれている[33-35]．ARMITAGE ら[33] は，*Orconectes nais* では 脂肪を除いた 肝膵臓と 卵巣の 乾燥重量との 間に 負の 相関が ある ことを 指摘し， *Uca annulipes* について PILLAY & NAIR[34] は肝膵臓で 蓄積された 脂肪が卵細胞の形成に関与している可能性を示唆し，

CLARKE[35] は，*Chorismus antarcticus* の肝膵臓に蓄積された脂肪が卵巣の成熟に伴い卵巣へ移動することを明らかにした．一方，これに対して HEATH & BARNES[36] は *Carcinus maenas* の肝膵臓の重量が季節的な変化を示さないことも報告している．シャコ成体における生殖腺の重量と肝膵臓の重量の周年変化は，産卵期を除いて両者がほぼ並行的な変化をみせること (Table 3)，*Chorismus antarcticus*[35] と同様に成熟時の重量の急激な増加に伴う肝膵臓の重量の減少が顕著である事実から，両者には強い関連のあること，特に肝膵臓に蓄積された物質が卵巣へ移動していることが示唆される．

TRAVIS[37,38] は，脱皮前後の *Panulirus argus* の肝膵臓の組織学的・組織化学的検討から，脱皮に必要な諸種のエネルギーの貯蔵器官としての肝膵臓の役割について，また，VONK[31] は無脊椎動物のカルシウムの貯蔵器官としての肝膵臓の役割について触れている．しかし，シャコ成体における肝膵臓と脱皮との関連性については，その乾燥重量の変化 (Table 3) からは，それらの間の明瞭な相関関係は指摘できない．このことは，HEATH & BARNES[36] が *Carcinus* で指摘したようにシャコの成長が貯蔵カルシウムよりも摂取物質中のカルシウムの直接利用に依存していることを示唆しているが，成長現象に関連する残された課題となろう．

甲殻類の日周活動と摂餌活動の関連性については，すでに *Panulirus japonicus*[39,40] や *Jasus lalandii*[41]，*P. longipes cygnus*[42] で報告されており，夜行性活動が摂餌とほぼ比例的な関連にあることが明らかにされている．また，水温の上昇が摂餌活動を活発化させることも実験的に確かめられている[42]．先に明らかにした結果は，一定規模の刺網に定時間経過後に羅網した個体数を表しているので，遊泳活動の日周期を反映していると考えてよいであろう．また，採集個体数と消化管内容物をもつ個体数がほぼ比例した関係にあることから，日周活動の様相はそのまま摂餌活動をも示唆している．したがって，シャコの周年にわたる摂餌活動の様相は冬から春にかけては不活発であること，春から活発化して主として夜間に摂餌を行うようになること，最も摂餌活動の活発な夏から秋にかけては周日摂餌活動を行うが秋から冬に至る期間は再び夜間摂餌型に移行することの諸点にまとめることができる．これまで，シャコは夜行型の日周期活動をとるといわれてきた[14] が，ここでえられた結果は春・秋の夜行型期，夏の周日型期，冬の不活発期という季節的に異なる相をとることを示すものであり，それは主として食物獲得が導因であると考えられる．このような摂餌活動の季節的な違いについてはこれまでに報告がなく，わずかに ROPES[43] や ERIKSSON ら[44,45] による *Carcinus maenas* で冬期の低水温によって摂餌が抑制されるという報告があるにすぎない．シャコの日周活動にみられる夜行型，周日型の季節的な違い (Fig. 14) の把握は生殖周期や体成長の型と関連するそれらへの物質供給の基礎となる摂餌活動の季節変化をあらわすものとして意義をもつものと思われる．

シャコ類の食物摂取に関しては，これまで食性や胃内容物の重量組成およびそれらの季節変化についてのいくつかの報告があげられている[1,16,17,47,48]．しかし，これらの諸知見はシャコ自然集団がどのような生物を摂取しているか，胃内容物量の体重に占める割合という相対的な摂食量とその季節的変動がどのようであるかについての知見を提供してはいるが，摂取された物質がどれほど消化・吸収され，それが体部位の成長へどのように寄与しているかという栄養摂取の動態については，未知の分野として残されていた．一般に，肉食動物の同化効率は85%ほど[49] といわれているが，十脚目および等脚目甲殻類については *Carcinus maenas*[46]，*Rhithropanopeus harrissii*[50] でそれぞれ88%，97%，また，*Cirolana harfordii*[51]，*Glyptonotus antarcticus*[35] では88%，90%以上と報告されている．先に明らかにしたように年間のエネルギー収支から算出したシャコ成体における同化効率は90～95%を示したが，この値はこれまでの十脚目および等脚目甲殻類のそれの示す範囲内にあるといえる．

これまで大型甲殻類のエネルギー収支に関する研究は，ほとんどが未成熟個体に関するもので，ERIKSSON & EDLUND[46] は，0齢の *Carcinus maenas* 個体での粗成長効率が43%，純成長効率が49%であること，KLEIN BRETELER[52] は，*Carcinus maenas* の若齢個体の粗成長効率が9～40%，純成長効率が56～76%であること，DAWIRS[53] は *Carcinus maenas* 幼生の粗成長効率が3.3%，純成長効率が14.8%であることを報告している．未成熟個体であっても，その発育段階の違いにより効率に大きな違いのあることが示唆され

てはいるが，今のところ一定の傾向を汲み取れるだけの知見は出そろっていないようである．WELCH[54] は，これまでの海産動物のエネルギー収支に関する諸知見をもとに，肉食者は同化効率が高く純成長効率が低い傾向にあることを指摘しており，本研究で明らかにしたシャコ成体個体の90%を越える高い同化効率と10%前後の低い成長効率は大型甲殻類の成体個体における生物生産効率の一例をあらわしたものといえる．

代謝損失エネルギーの測定については，これまでの知見の多くが標準代謝量を扱うにとどまり，摂餌や活動によって消費されるエネルギーに触れたものは少ない．NELSON ら[55,56] は，*Macrobrachium rosenbergii* の摂餌による呼吸量の増加（Specific dynamic effect）は，通常代謝（routine metabolism）の40%に達すると報告しており，LOGAN と EPIFANIO[57] は *Homarus americanus* の幼生と若体での摂餌代謝量（fed metabolism）が通常代謝の約1.5倍に，また，MCLEESE[58] は *Homarus americanus* 成体の摂餌による酸素消費量がそれの2倍に達すると報告している．また，MCFARLAND & PICKENS[59] によると *Palaemonetes vulgaris* の活動代謝は標準代謝の2倍以上にも及んでいる．

シャコの周年にわたる活動の様相は，先に明らかにしたように，夜間に限られる時期が年のほぼ半分を占め，日中にもみられる時期と周日ほとんどみられない時期とが残りの部分を分けている．本研究ではこのような摂餌活動の様相とこれまでの知見から平常代謝を標準代謝の2倍と見積もったが，周年にわたるシャコの遊泳や摂餌に伴う活動の詳細な把握により，より妥当な代謝損失量の見積りが必要となろう．また，特異動的作用による呼吸量の増大は代謝損失量の中で比較的大きな値をとり，KLEIBER[60] によると哺乳類では同化エネルギーの15〜30%に及ぶとされている．したがって，呼吸による代謝損失量のなかでの特異動的作用による損失量をエネルギー収支に位置づけることが必要となろうが，この点に関しては本研究では明らかにしえなかった．今後の課題となろう．

体長の違いによるエネルギーの摂取量や転換比率の違いは，体成長にむけられるエネルギーと生殖腺の発達にむけられるエネルギーの違いなどと関連して，年齢や成熟段階に対応した種個体群内での個体の役割の違いを反映したものと考えられる．本研究に用いた体長12cm以上の個体は，生殖周期の項で触れたように，シャコの産卵期の6月においてすべて生殖腺指数が9以上で成体とみなしたが，体成長の項で明らかにした成長のパタン，食物摂取の項で明らかにした食物摂取量の季節変化，およびエネルギー転換の型からも基本的には同一の様相を示していると結論しうる．以上のことから，成体の生活環は食物摂取にはじまり生殖腺の発達および体成長へと配分されるエネルギー転換の様相から，いくつかの周期的な段階に分けられると考えた．それは次のような年周期である．

1） 脱皮と体成長の時期（8月〜11月）：脱皮による体組織の成長がみられる．外骨格の更新とそれに伴う体組織の増大は，高い食物摂取量に支えられ，基本的な体組織の増大が終了した後も，余剰のエネルギーは生殖腺（雌）や肝膵臓の成長に引きつがれる．

2） 越冬期（12〜2月）：水温の低下を基本的な要件として，摂餌が不活発となり，活動それ自体がおさえられる．

3） 生殖腺の成長・成熟期（3月〜5月）：水温の上昇とともに摂餌が活発となり，貯蔵エネルギーは，生殖腺の増重・成熟にむけられる．

4） 産卵期（6月〜7月）：生殖細胞の放出が行われる．

V 要約

シャコは，わが国浅海域の砂泥底に広く分布し，地域的には重要な漁獲対象種となっている．

これまで，シャコの個体群動態やその基礎的な生態学的事象を扱った知見は少なく，資源管理を考慮した漁業技術を確立する上でも，増養殖の可能性を探りだす上でも，本種の生活様式の解明が強く求められている．

本研究は，シャコの生物生産を中心とした生態学的事象を明らかにする立場から，生殖腺と体の成長およびこれを支える食物摂取について明らかにし，これらの相互関連からシャコ成体の生活環を把握した．得られた成果は，次のように要約される．

(1) シャコ成体の生殖腺の成熟過程は，雌雄生殖細胞の発育に伴う形態的特徴から，雌で4期，雄で5期に区分される．さらに，生殖腺の成熟過程と生殖腺重量の季節的な変化から，シャコ成体の生殖周期は，雌個体群では，回復期：8～9月，発育期：10～11月，前成熟期：12～2月，成熟期：3～5月，産卵期：6～7月，雄個体群では，回復期：7月，発育期：8～9月，前成熟期：10～12月，成熟期：1～4月，放精期：5～6月という1年を1周期とする過程をたどる．

(2) 陸奥湾におけるシャコ自然個体群の体長頻度分布の解析および室内水槽内での飼育個体群の脱皮の様相から成長を検討した結果，シャコの体長増大は脱皮により非連続的になされ，体長12cm以上の成体では脱皮期間は8月から10月，成長式は

$$L_{n+1}=0.755L_n+4.743$$

であらわされる退行性等比成長型を示す．

体重の変化は，体長と同様脱皮後に大きな増大を示し，このことは雌雄個体に共通しているが，雌個体ではさらに卵巣の成熟と産卵に伴う体重の増減が顕著であり，雄個体と大きな違いがある．

(3) 外骨格，肉質部，肝膵臓および卵巣の乾燥重量の周年変化から判断して，脱皮現象に伴う重量の増大は，主として新生殻と体肉質部の増重によってもたらされる．また，雌の卵巣の乾燥重量は，肝膵臓と共に季節的に大きな変化を示し，産卵に関わる両者の関連性の強いことを示している．

(4) シャコは，食物獲得を導因として，春・秋には夜行型，夏は周日型，冬は不活発となる日周期をとる．また，甲殻類，貝類，魚類を高い割合で摂食する．

(5) オキアミ餌料で飼育した成体個体の日間摂餌量は，12月から2月にかけて20～70mg dry wtの極小値をとり，その後増加して8～10月には270～370mgの最大値をとるが，11・12月には急激に減少してほぼ100mg以下となる．また，同化効率は，季節による大きな変動が少なく，概ね90%ほどの水準にある．

(6) 個体の生産過程は，摂取量－排出量＝同化量＝体成長量＋生殖腺成長量＋代謝損出量であらわされ，シャコ成体個体は，年間190～240kcalを摂取してそのほぼ90%を同化する．この同化エネルギーの大きな部分は呼吸として失われるが，残余のエネルギーは雌での19～26kcal，雄での約12kcalが体を構成する各部位に蓄積されて成長という形をとる．このうち，脱皮によって雌雄とも3～5kcal 約2%が体外に放出され，また，雌では，7～14kcalが生殖腺の成長にあてられるが，産卵によってその85～90%が生殖物質として体外に失われる．摂取したエネルギーが新しい組織に転換される割合（粗成長効率）は，雌で9～11%，雄で5～6%である．

(7) 生殖腺の成長および体成長と食物消費量との相互関係を検討し，摂餌にはじまり食物同化をへて成長に至るまでの一連のエネルギー転換の観点からみると，シャコ成体の生活環は，次の4期に整理される．

1）脱皮と体成長の時期（8月～11月），2）越冬期（12月～2月），3）生殖腺の成長・成熟期（3月～5月），4）産卵期（6月～7月）．

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Acoustic Survey of Spawning Sardine, *Sardinops melanosticta* in the Coastal Waters of West Japan

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Annual acoustic surveys have been conducted in winter for spawning sardines by the R/V "Yoko Maru" since 1984. These distribution and abundance studies were made using a quantitative echosounder (FQ-50, Furuno Electric Co.) at 50 KHz. The survey area, extending from 33°N to 31°N along the shelf of the west coast of Kyushu Island, was transected with a 5 nautical mile survey grid.

Echo traces were identified using mid-water trawl gear. A TV camera was used occasionally for observations of the fish schools. The trawl catches and TV observations suggested that the major cause of sound scattering was spawning sardine.

Prior to the abundance survey, target strength for spawning sardines was determined by measurements of various densities of sardines in a submerged cage. These derived values were used for conversion of digital echo integration to sardine abundance during the acoustic surveys.

The acoustic method was found applicable to behavior observations and stock assessment of highly aggregated concentrations of spawning sardines.

INTRODUCTION

The spawning stock of sardine (*Sardinops melanosticta*) migrating to inshore waters of west Japan is an important fish stock especially for the Japanese purse seine and set net fishery (Fig. 1). The Seikai Regional Fisheries Research Laboratory has conducted acoustic surveys to monitor the distribution and abundance of this spawning stock of sardines for management purposes since 1984, using the R/V "Yoko Maru" which was equipped with a Furuno FQ-50 echo sounder.[1,2] Mid-water trawl sampling to identify echo sign and provide biological data on target fish was also conducted during the surveys. Target strength (TS) data used to estimate abundance from the surveys was obtained from experiments in 1984.

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Fig. 1. Migration pattern of Kyushu stock of spawning sardines. Numbers indicate the day of first catches in various areas during the 1984 season for the purse seine fishery (A, B, F and G) and for the set net fishery (C, D and E).

TARGET STRENGTH EXPERIMENT

Target strength measurements were made from live fish contained in a submerged net cage (10 mm mesh nylon net) which was cylindrical in shape and 3 m high and 2.16 m in diameter. The cage was located 3 m under the transducer (Fig. 2). The integration layer (1 m) for measuring target strengths was selected from the portion of the cage receiving minimum reflection from the ceiling and the floor net. Both hull-mounted and external transducers were calibrated with a standard hydrophone.[3,4] The control settings of the echo sounder during the TS experiments are shown in Table 1.

Live sardines for the TS experiments were caught by purse seine and held one day in a large live cage prior to the experiment. The specimens averaged 17.9 cm in body length and 60.1 g in body weight.

Backscattering strengths (SV) were measured with the TS cage empty and with the cage stocked with 3,005, 1,997, 987, 483, and 200 fish using echo integration techniques at 50 and 200 KHz (Suppl.-fig. 1). The echogram, visual observations and TV monitoring suggested that the fish were nearly uniformly distributed

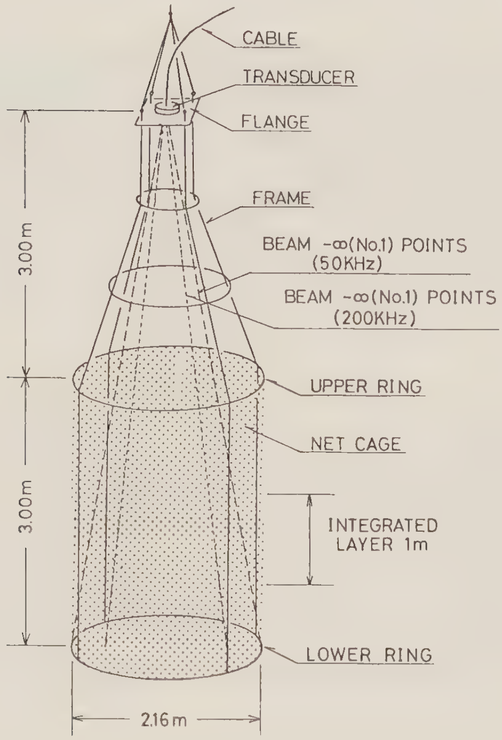


Fig. 2. Illustration of the TS net cage.

in the cage over an adequate time interval.

The relationship between fish density in the cage ρ (kg/m^3) and backscattering strength, based on the measurements obtained from the TS experiment, was

Table 1. Control setting of echosounder Furuno FQ-50 during TS experiment and acoustic survey

	TS experiment		Acoustic survey	
Acoustic Frequency	50 or 200		50	KHz
Pulse Width	0.6		0.6	ms
Absorption Loss	12.3	50.4	12.3	dB/km
TVG	20		20	log R
Directivity Index	0.011	0.007	0.011	
Attenuator	40	30	30	dB
Sound Velocity	1500		1500	m/s
Print Interval	100 Pulse unit		0.5 mile	
Range	1 m range		10-200 m depth	
	(4 to 5 meters from transducer)		(10-20 m and 20 m intervals)	
Ship Speed	—		9-11	knot

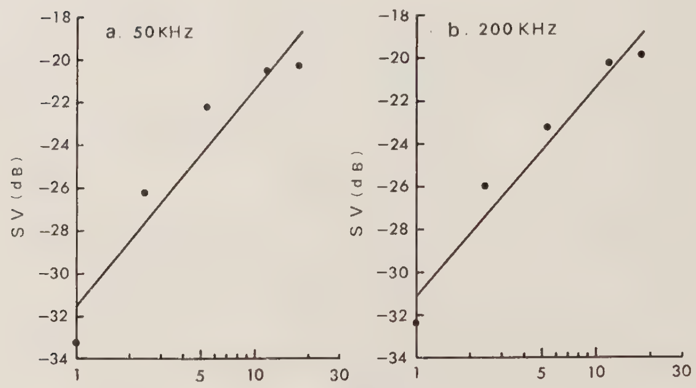


Fig. 3. Relationship between fish density ρ and backscattering strength (SV) for spawning sardines based on the TS experiment.
a. $SV=-31.5+10.2\log\rho$ b. $SV=-31.2+9.9\log\rho$

shown by the following regressions (Fig. 3):

$$SV=-31.5+10.21\ \log\rho,\ \text{(at 50 KHz)}$$
$$SV=-31.2+9.91\ \log\rho,\ \text{(at 200 KHz)}$$

Thus, the TS kg of the spawning sardine (60.1 g in average body weight) was given as −31.5 dB (50 KHz) and −31.2 dB (200 KHz).

For the TS experiment, it would be desirable to have the fish density in the cage comparable to that in the sea. However, fish densities in the cage were probably higher than those under natural conditions, even when sardines are highly concentrated for spawning (Suppl.-figs. 2 and 3).

ACOUSTIC ASSESSMENT SURVEYS OF SARDINES

The acoustic surveys were conducted along 5-mile grid tracklines during both night and day. The survey area extended from 33°N to 31°N, covering the shelf area along the west coast of Kyushu Is.

Control settings of the echo sounder during the survey are shown in Table 1.

Table 2. Outline of sampling mid-water trawl nets

Trawl net	Height of net opening (m)	Length of net (m)	Average towing speed (knot)
Yoko-I	28-30	110	3.0
Yoko-II	18-20	60	3.5
Yoko-III	20-22	86	4.5

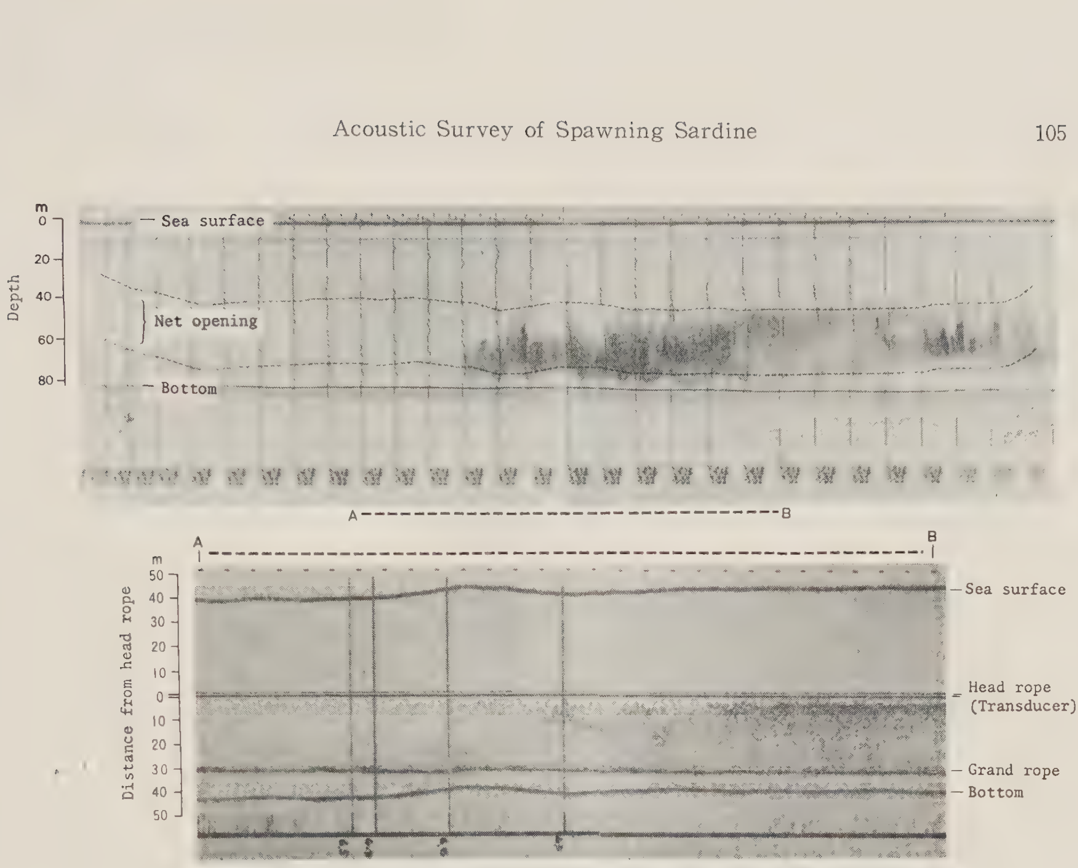


Fig. 4. Echogram of spawning sardines and the track of the trawl from the echosounder (top), and from a netsounder (bottom).

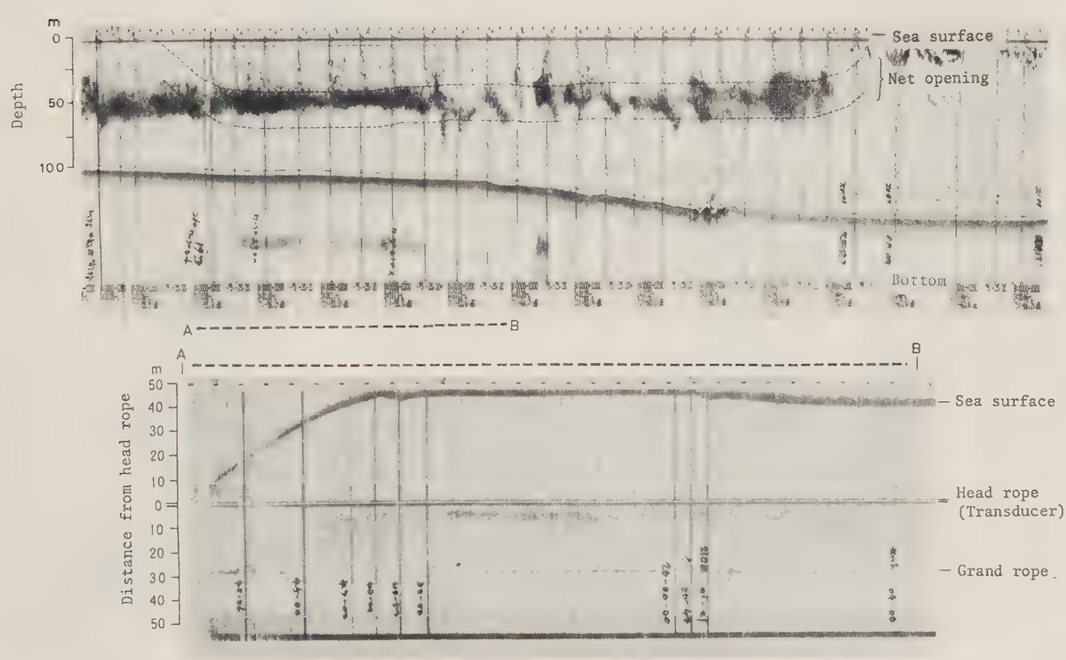


Fig. 5. Echogram of spawning sardines and the track of the trawl from the echosounder (top), and from a netsounder (bottom).

Mid-water trawl nets of 3 types were developed for the acoustic surveys (Table 2 and Suppl.-fig. 4). Trawl sampling was generally carried out with the Yoko-II net because of its high performance. While fishing at a towing speed of 3-4 knots, the vertical mouth opening of the trawl was 18-20 m. Haul duration was variable and was kept to the minimum considered necessary to assure accurate species identification and adequate samples of biological data.

The mid-water trawl hauls were not made in a systematic manner, but instead aimed at selected aggregations of fish as shown by the echo sign (Fig. 4 and 5).

Catches were approximately 95% sardines (15-22 cm in body length, 35-110 g in body weight). It is notable that negligible or no catches were made during daytime trawl hauls.

The spawning sardines were distributed widely over the survey area. The vertical distribution of the sardine in the survey area is shown in Suppl.-fig. 5. Typically, high concentrations of fish were encountered in the bank area and near the shelf edge, for example see K transect in Supple.-fig. 5. Fish density was very low off the shelf. The geographic distribution of the spawning sardines is shown

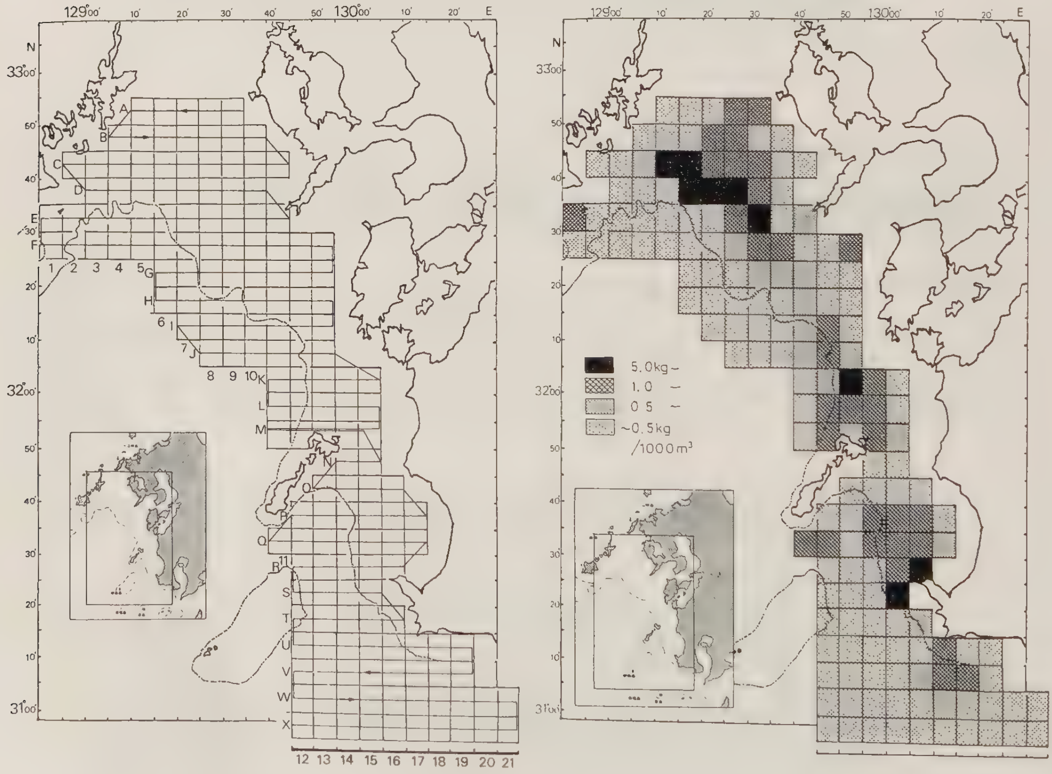


Fig. 6. Cruise track of the acoustic survey for spawning srdines, Feb. 1-4, 1986 (left) and the geographic distribution of fish (right).

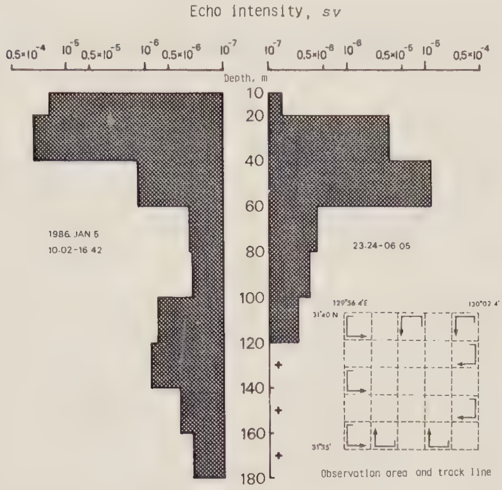


Fig. 7. Comparison of echo intensity for spawning sardines between daytime and nighttime based on the observations for an area of high fish concentration, Jan. 5, 1986.

in Fig. 6.

According to the acoustic observations, there were differences in schooling behavior between daytime and nighttime.[4,5] The fish had a greater vertical distribution during the day than during the night. Highest concentrations were observed in the shallowest layer during the day (Fig. 7).

Assuming that nearly all the echo sign detected during the survey were sardines, abundance of the fish was calculated by applying the TS kg value to the average backscattering strength in each grid cell. The stock size of the spawning sardines was estimated to be 2.8 million tons.

CONCLUSIONS AND FUTURE RESEARCH

The acoustic method was found to be useful for observations of behavior and stock assessment of high aggregations of spawning sardines.[6–8]

Multi-vessel surveys will be needed in the future to improve the precision of stock size estimates, because the movements and migrations of sardines are generally rapid. Surveys of this type will also be effective for studying the structure and behavior of fish schools that change with time of day. It will also be desirable to further develop our sampling gear and techniques, and to develop an underwater optical monitoring system to support the acoustic field surveys and the TS studies.

ACKNOWLEDGEMENT

The authors are grateful to Mr. S. MORITA, director of Fisheries Resources Division Seikai Regional Fisheries Research Laboratory, for his valuable suggestions and encouragement during the study. They thank the crew of R/V "Yoko Maru" of the Laboratory for their kind assistance on board the ship.

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九州西海域におけるマイワシ産卵群の音響調査

竹下貢二・小川信次・三谷卓美
濵田律子・乾　栄一・久保田勝彦

抄　録

九州西海域に冬季来遊するマイワシ産卵群について，1984年以降音響手法による資源調査を実施した．又1984年の調査時にはケージ法による標的強度（TS）測定試験を行った．資源調査は五島灘から薩摩半島周辺に至る水深約200m以浅の海域について実施した．調査海域内では，緯度5分間隔で設けた定線を航走しつつ，計量魚探機（古野電気㈱製，FQ-50）を用いて，体積散乱強度（SV）の測定及び魚群の観察を行った．測定は周波数 50KHz，積分周期 0.5マイルで行った．魚探調査によって濃密な魚群が認められた水域においては，資源調査用として開発した中層トロールを用いて漁獲試験を行い，魚種や魚体の大きさ等の生物情報を収集した．又水中テレビカメラによる魚群観察も適時試みた．それらの試験や観察結果によると，調査海域内に分布する魚群の大部分はマイワシ産卵群であると考えられた．マイワシ産卵群は調査海域のほぼ全域にわたって分布しているが，濃密な分布は海底にバンクをもつ海域や陸棚縁辺部にあたる海域にみられた．陸棚を外れた沖寄りの海域での魚群密度は極めて低かった．又魚群の形成状況には昼夜による差異が認められた．魚群量については TS 測定試験から推定した TS_{kg} 値（−31.5dB）を魚探調査から得られた SV 値（緯・経度5分のます目毎の平均値）に適用して試算した．測定された SV 値がすべてマイワシによるものと見做すと，調査海域内の1986年の魚群量は約280万トンと見積られた．

Suppl.-figs. 1~5.

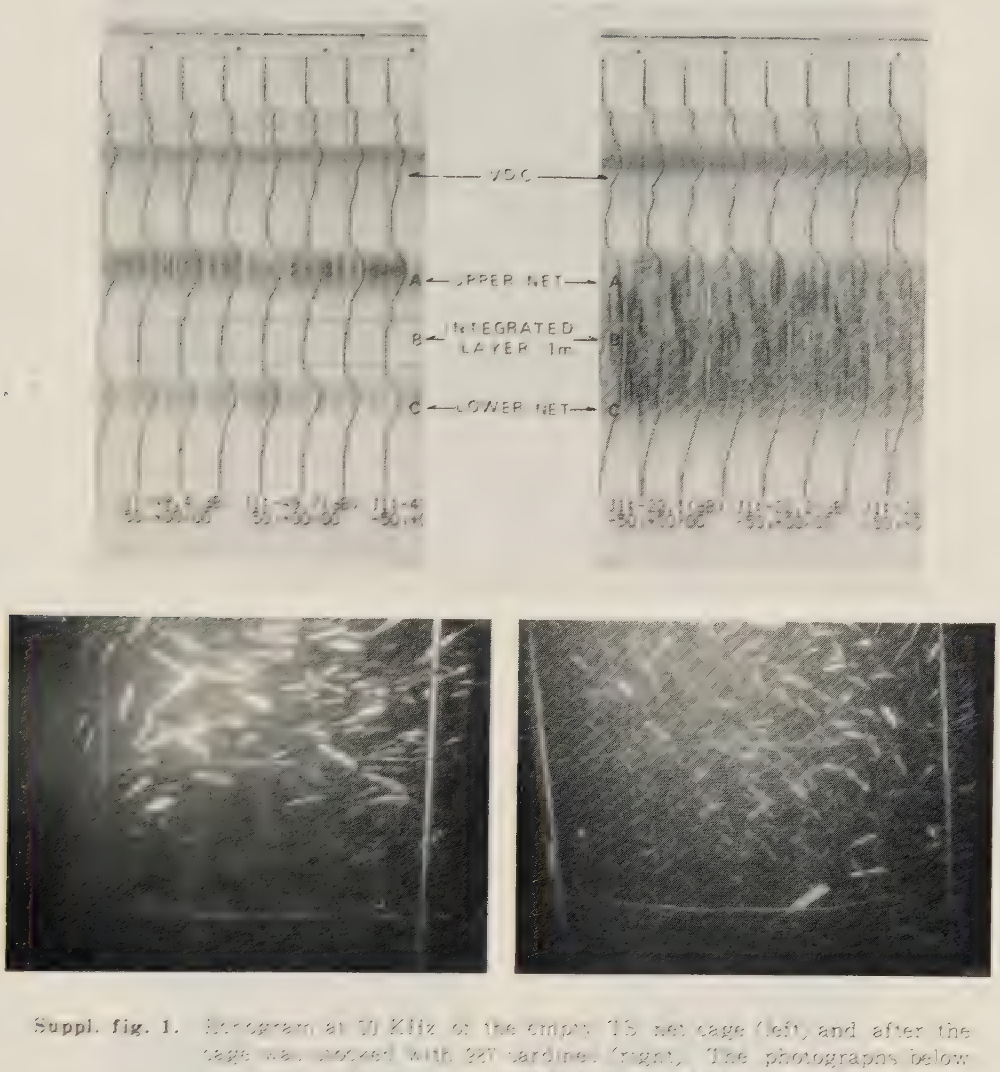
Suppl. fig. 1. Echogram at 50 KHz, of the empty TS net cage and after the cage was stocked with sardines, and the photographs of live sardines in the cage.

Suppl. fig. 2. School of spawning sardines monitored by an underwater TV camera.

Suppl. fig. 3. A catch of sardines on deck by trawl sampling.

Suppl. fig. 4. Schematic diagrams of the mid water trawl nets used for the acoustic survey of spawning sardine.

Suppl. fig. 5. The vertical distribution of spawning sardines as shown by the echo-sounder and the actual echo trace during the 1986 acoustic sarvey



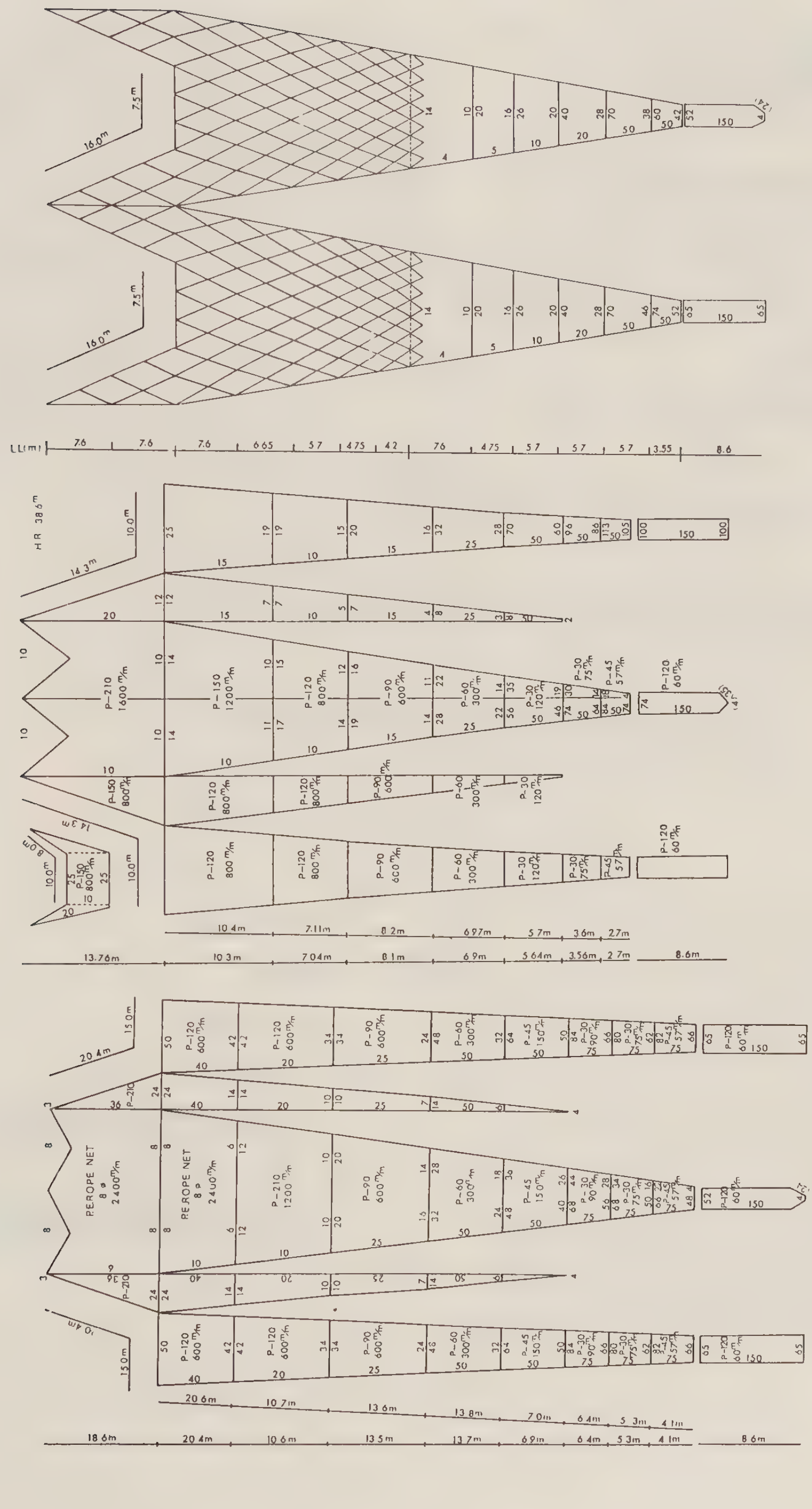
Suppl. fig. 1. Echogram at 70 KHz of the empty TS net cage (left) and after the cage was stocked with 337 sardines (right). The photographs below are sardines in the cage (1397 fish, left and 3005 fish, right).



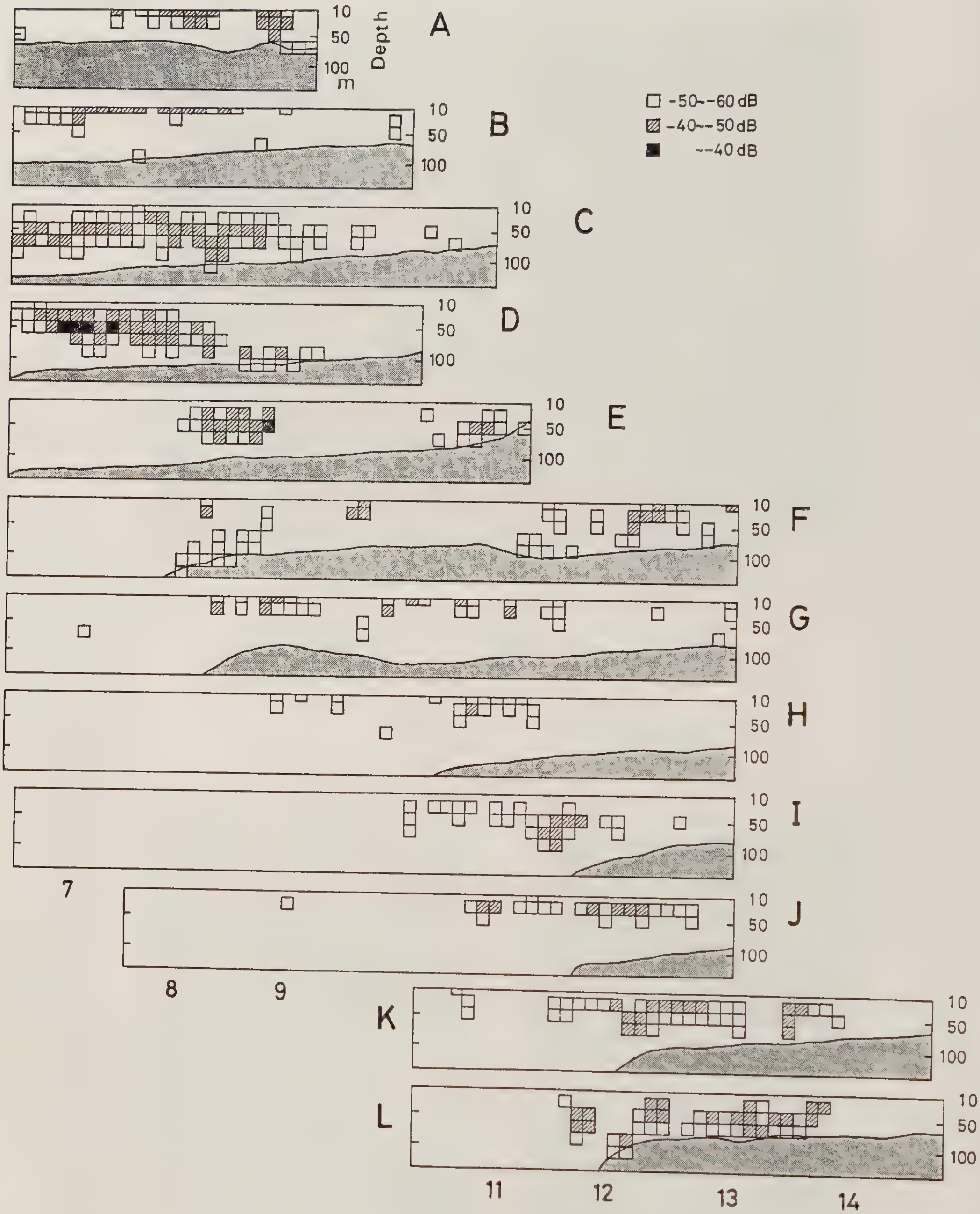
Suppl.-fig. 2. School of spawning sardines monitored by an underwater TV camera.



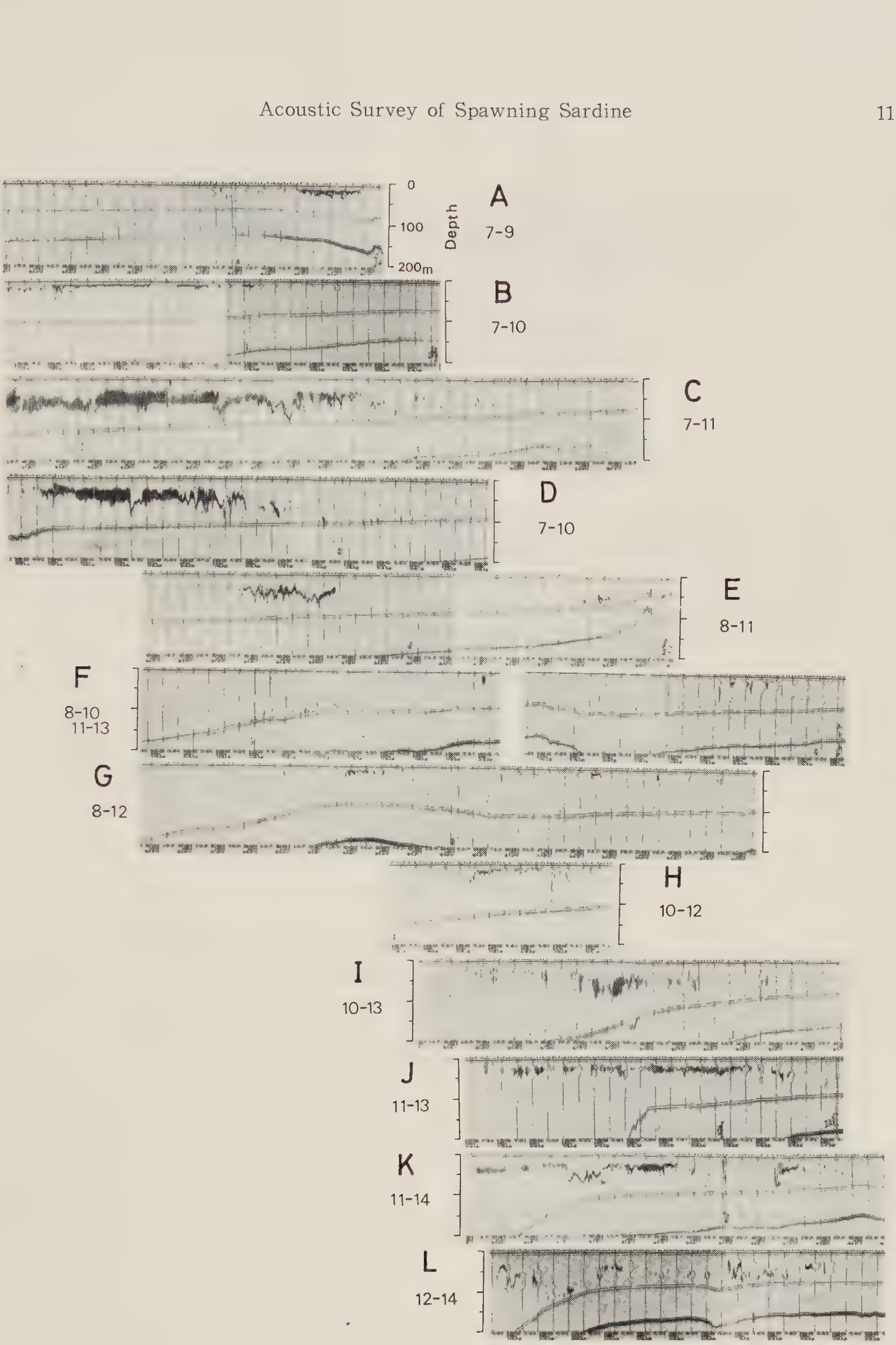
Suppl.-fig. 3. A catch of sardines on deck by trawl sampling.



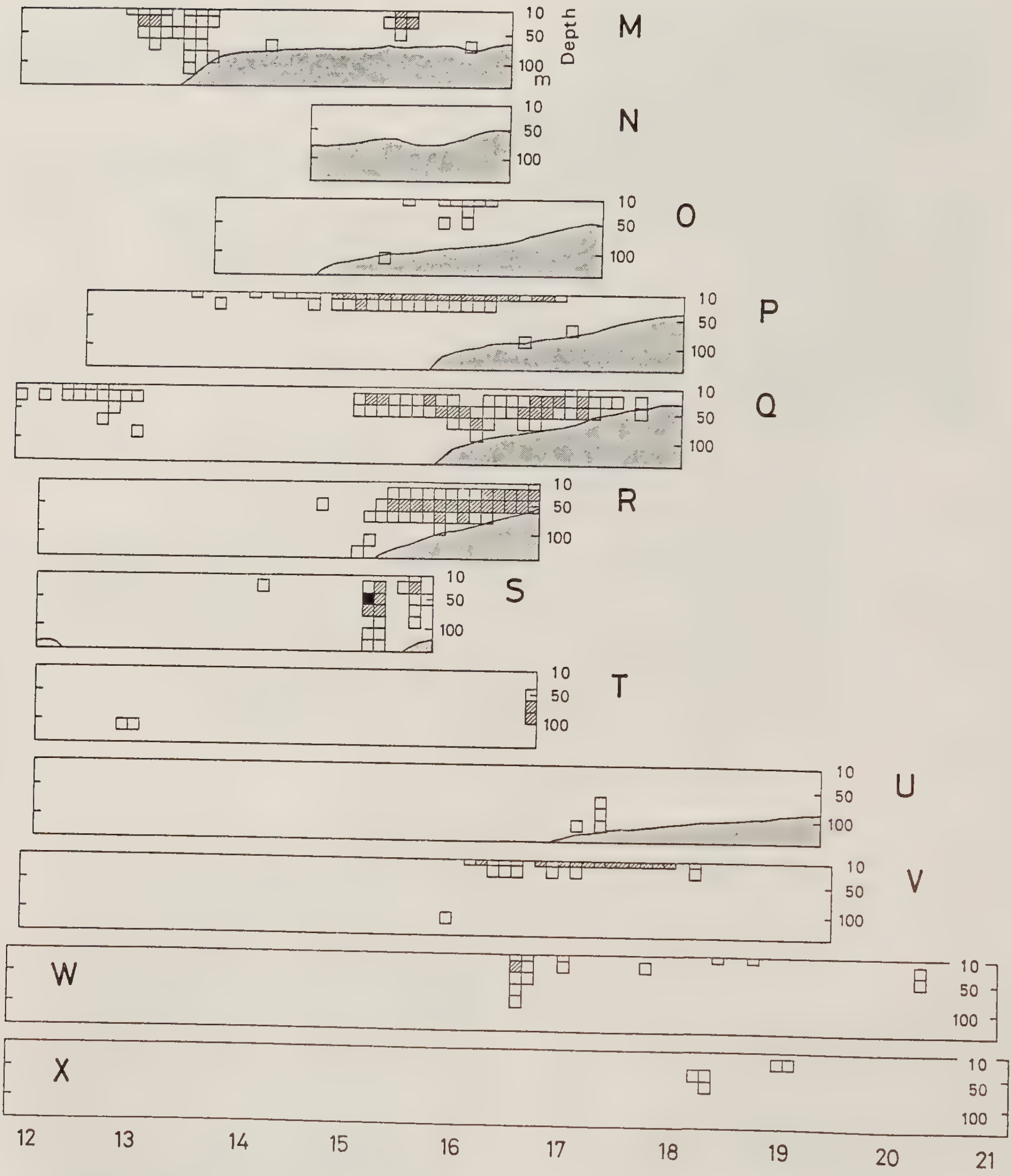
Suppl. fig. 4. Schematic diagrams of the mid-water trawl nets used for the acoustic survey of spawning sardine. Yoko-I (left), Yoko-II (middle) and Yoko-III (right).



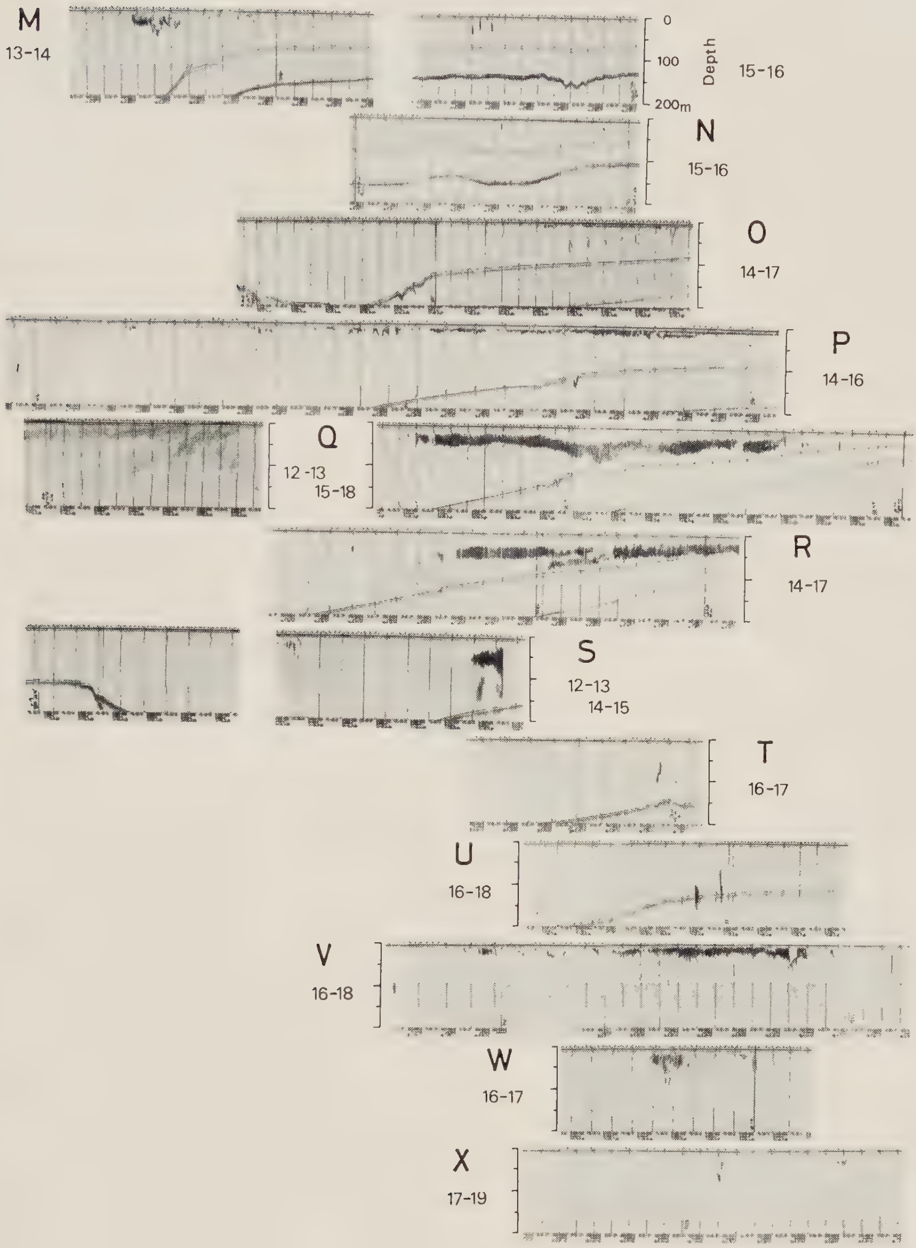
Suppl. fig. 5. The vertical distribution of spawning sardines as shown by the echosounder (left) and the actual echo trace (right, next page) during the 1986 acoustic sarvey (see cruise track in Fig. 6).



0
100
200m
Depth
A
7-9
B
7-10
C
7-11
D
7-10
E
8-11
F
8-10
11-13
G
8-12
H
10-12
I
10-13
J
11-13
K
11-14
L
12-14



Suppl.-fig. 5. Continued.


M
13-14
0
100
Depth
200m
15-16
N
15-16
O
14-17
P
14-16
Q
12-13
15-18
R
14-17
S
12-13
14-15
T
16-17
U
16-18
V
16-18
W
16-17
X
17-19

Length Cohort Analysis of Common Mackerel, *Scomber japonicus*, Tsushima Warm Current Stock

Daniel LIMBONG*, Kohachi HAYASHI**
and Yoshiharu MATSUMIYA***

ABSTRACT

Some aspects of the dynamics of the common mackerel, *Scomber japonicus* (Tsushima warm current stock) were examined by length cohort analysis developed by Jones.[1] Calculations were made on the mean catch in number which was derived from catch data over the period 1974-1984. Various combinations of input L_∞ (length infinity) and M/K (M=natural mortality coefficient, K=growth rate) were used to determine stock size, exploitation rate, and the effects of changes in fishing effort on the yield per recruit.

INTRODUCTION

Common mackerel, *Scomber japonicus*, is one of the important commercial stocks of pelagic fish in Japan. This species is widely distributed in the sea around Japan. NAKAI *et al.*[2] concluded that the Japanese common mackerel population is comprised of at least three systematic fractions; the western Kyushu group, the Japan Sea group, and the Pacific group. Furthermore, WATANABE[3] explained that the Pacific group is split into the Honshu group and the Shikoku group; and the western Kyushu group is split into the northern Tsushima warm current group and southern Tsushima warm current group.

Investigations on the population of common mackerel in southwest Japan Sea and the East China Sea by OHKAWA,[4] OUCHI and HAMASAKI[5] showed, as a first approximation, that there are three subpopulations in this area, namely, the south

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East China Sea, the west East China Sea and western Kyushu subpopulation. Further investigation of IIZUKA and HAMASAKI,[6] however, concluded that common mackerel in this area consists of only two subpopulations, the East China Sea subpopulation and the Tsushima warm current subpopulation. Recent investigation by HAYASHI and HAMASAKI[7] (Fig. 1) reached the same conclusion as Iizuka and HAMASAKI.

In the light of all the available information, an attempt has been made in this study to assess the dynamics of Tsushima warm current stock. Several aspects of the dynamics of this stock will be described in this paper by length cohort analysis and yield assessment techniques.

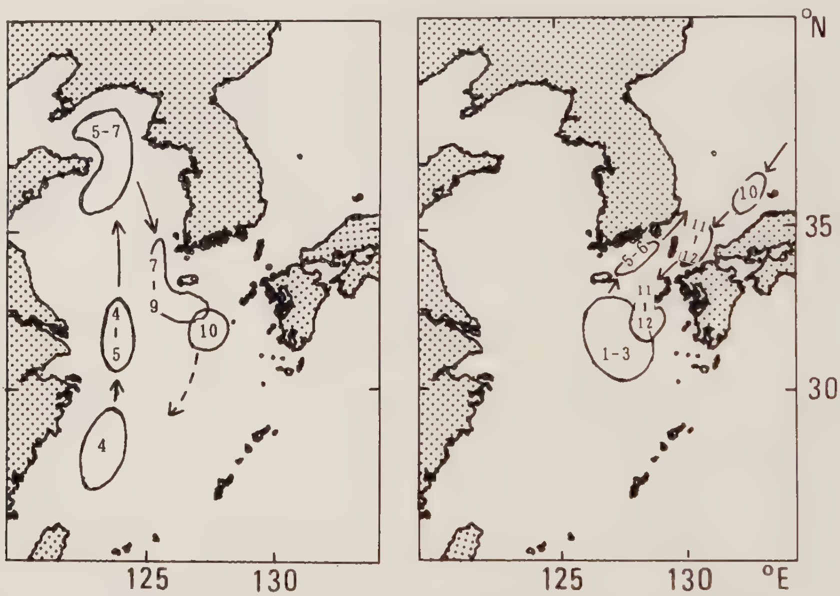


Fig. 1. Migration pattern of common mackerel East China Sea subpopulation (left) and Tsushima warm current subpopulation(right). Areas bounded represent the fishing area, numbers and arrows indicated the period by month and the migration route. After Hayashi and Hamasaki.[7]

DATA SOURCE

On the basis of fisheries statistics compiled by the Fisheries Agency, the catch data for southwest Japan Sea and the East China Sea common mackerel have been tabulated and analysed by the Shimonoseki Branch of Seikai Regional Fisheries Research Laboratory. The catch in number for each length is obtained from catch data by means of the average number of fish per box and length composition of each market size category. Details of the method of analysis are given by MAKO[8]

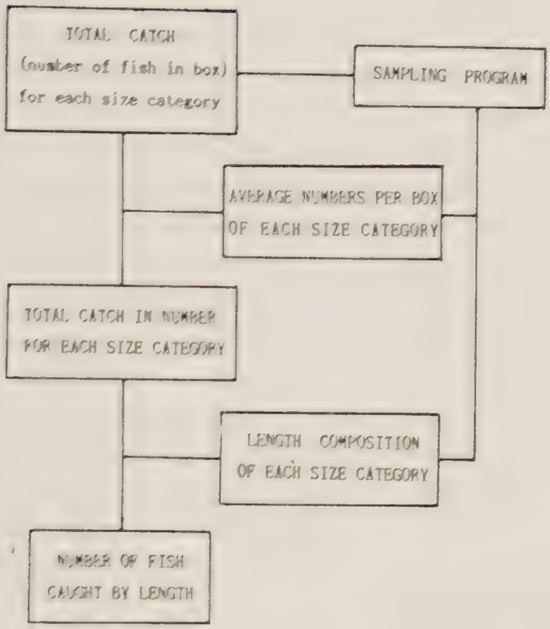


Fig. 2. Graphical representation of the estimation procedure of number caught by length of common mackerel from the southwest Japan Sea and the East China Sea.

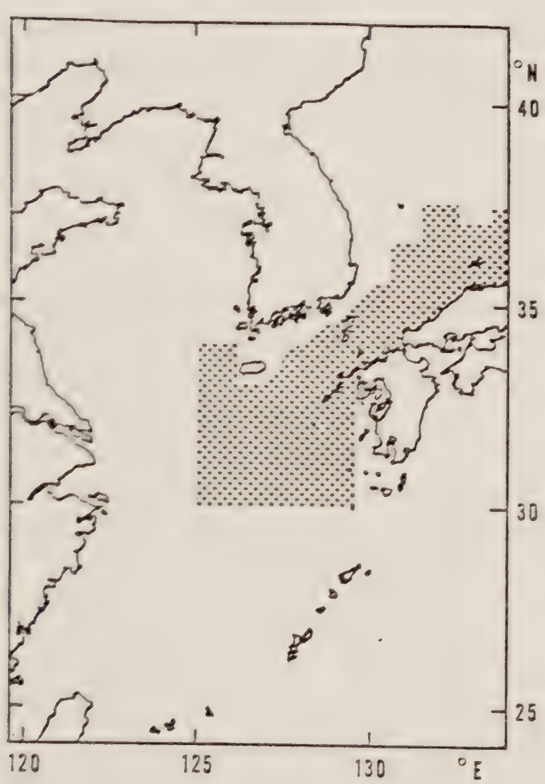


Fig. 3. Map indicated by shade showing the arbitrary section of the sea area from which the catch data of Tsushima warm current stock had been compiled.

and the procedure is briefly presented in Fig. 2.

Because the catch data were provided according to the fishing position, the number of common mackerel caught by the purse seine fishery of the large type category from the Tsushima warm current for the period 1974–1984 had been compiled on an arbitrary section of the sea area as shown in Fig. 3. Of course, the total catch of common mackerel in this area consists of fishes from both stocks. However, based on the available knowledge of time-space migration pattern of both stocks as shown in Fig. 1, catch data of the East China Sea stock were split out and it was assumed that the remainder was representative of the catch data from the Tsushima warm current stock.

The spawning season of the stock mostly occurs in April (IIZUKA and HAMASAKI[6]); accordingly, catch data have been grouped into annual periods, from April of one year to March of the next to relate approximately to the year classes (cohorts) rather than calendar year. Configuration of these data is presented in Appendix 1.

COHORT ANALYSIS

Estimates of stock size and exploitation rate were obtained by Jones's length cohort analysis. Since detailed explanations of the method are given in JONES,[9,10] discussion here will be limited to the source and nature of input data and parameters. Principal input data and parameters for this technique consists of : 1) number of catch by length, 2) value of L_∞ (length infinity), 3) value of M/K (M=natural mortality coefficient) and 4) value of F/Z for the largest group (Z=total mortality coefficient and F=fishing mortality coefficient).

Since the amount of fish rejected at sea was very small, it has been assumed that no rejection occurred. Thus, the estimated number landed can be considered as the number actually captured. Representative length composition of steady state situation is required to fulfil the assumption of a steady state condition which underlies length cohort analysis ; however, in practice it is not likely to be available. JONES[10] suggested a useful approximation for this problem by determining the average length composition over a period of as many years as possible. Therefore, the analysis was carried out using the mean value of number caught during the period 1974–1984.

The following information on growth of the stock :

$$L_t = 401\{1 - e^{-0.41(t+0.72)}\}$$

$$L_t = 380\{1 - e^{-0.63(t+0.98)}\}$$

$$L_t = 399\{1 - e^{-0.56(t+0.47)}\}$$

is available from ANN,[11] OUCHI[12] and IIZUKA and HAMASAKI,[6] respectively. This information is not suitable for length cohort analysis, since the largest length in the catch data is greater than the values of L_∞ in these equations. As pointed out by JONES,[10] with regard to the values of L_∞ and K it is not necessary to use the best value, because in reality, there are two underlying relationships. One is between length and age, in which there is a mean length corresponding to each age, and the other between age and length, in which there is a mean age corresponding to each length. The growth curve constructed from the first relationship will give a value of L_∞ smaller than the largest length in the catch data, while the value of L_∞ obtained by the last relationship will not be smaller than the largest length in the catch data. All the available values of L_∞ mentioned above are smaller than the largest length in the catch data because they used the first relationship.

In choosing the value of L_∞, the method provided by POWELL[13] and empirical equation $L_\infty = L_{max}/0.95$ proposed by PAULY[14] (L_{max}=largest length in the catch), have been used and values of $L_\infty = 420$ mm and $L_\infty = 450$ mm were obtained, respectively. Both values were used in the analysis, since these values appear to represent the probable range of this parameter. Application worksheet of Powell's method is given in Appendix 2.

As described by JONES,[10] compatible values of K for each value of L_∞ were determined from Ford-Walford plot with one annual increment of the youngest age group which is available from IIZUKA and HAMASAKI.[6] For value of $L_\infty = 420$ mm, value of K is calculated as:

$$
\begin{aligned}
e^{-K} &= (L_\infty - L_2)/(L_\infty - L_1) \\
&= (420-301)/(420-224) \\
&= 0.607 \\
\therefore K &= 0.5
\end{aligned}
$$

Similarly, if $L_\infty = 450$ mm, the value of $K = 0.42$. It should be noted that the calculations have been based on the generalized von Bertalanffy growth formula (PAULY[15]).

As there are no reliable data on natural mortality coefficient, trial with input values of M/K ranging between 0.4–3.0 were done according to BEVERTON and HOLT[16] who found that value of M/K lies largely in the range 0.5–2.5 for many fish species. Compatible values of M in the range value of M/K were assumed to be constant for all length groups.

Sensitivity analysis of the different input values of F/Z for the largest fish group had been done by Jones[10] and he found that significantly different result arises only when the final value of F/Z becomes very small. By this result he concluded that in the heavily exploited stock, the choice of value for the final F/Z is not likely to make a critical effect on the calculations. It is reasonable to say

that the Tsushima warm current stock has been heavily exploited, since the total annual catch during the period of concern shows a decreasing trend (Fig. 4). On these grounds all calculations were done assuming that the value of F/Z for the largest fish group was 0.8. An example of calculation procedure is given in Appendix 3.

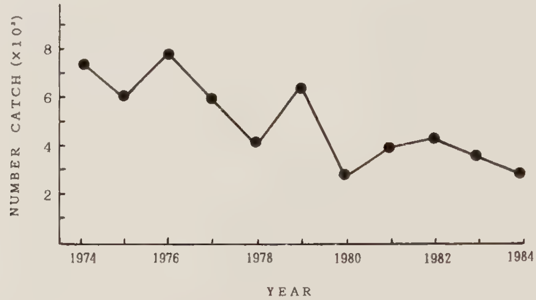


Fig. 4. Estimated number of common mackerel caught from Tsushima warm current stock by the large type purse seiner during 1974-1984.

STOCK SIZE AND RECRUITMENT

Given combinations of L_∞, K, and M/K, the estimated mean numbers in the sea were calculated and the results are given in Fig. 5. It is conceivable that the estimated stock size increases as the value of M/K increases and decreases with the bigger value of L_∞.

Since the estimated number for each length group is available, it looks possible to estimate annual recruitment. As an approximation, it may be supposed that the number attaining a length of 145 mm each year is equivalent to the annual recruit-

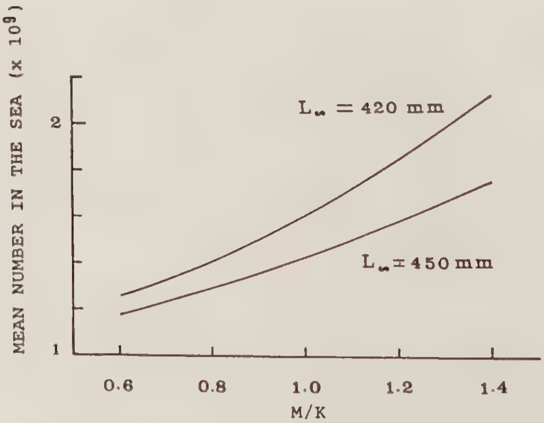


Fig. 5. Estimated mean stock size plotted against value of M/K.

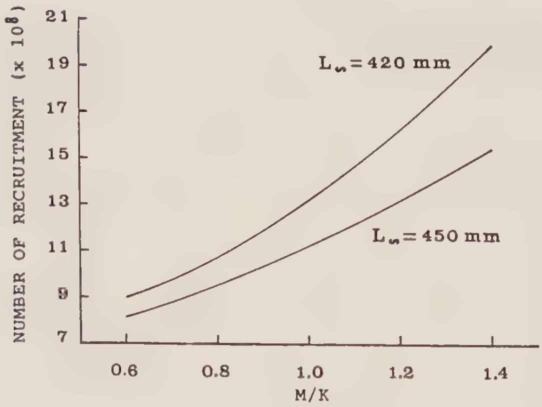


Fig. 6. Estimated annual recruitment plotted against value of M/K.

ment of a year class which has a mean age corresponding to the length of 145 mm. The estimated annual recruitment plotted against value of M/K is presented in Fig. 6.

YIELD PER RECRUIT ANALYSIS

The estimated fishing mortality coefficient (F) provided by cohort analysis was used to determine the effects on yield per recruit of changes in the value of F. Yield assessment method (for F varies with age) of Beverton and Holt[17] was repeatedly used to provide an estimate of maximum yield per recruit corresponding to the changes of F values. Fig. 7 shows the relationship between values of M/K and the percentage changes in the value of F required to give the maximum yield per recruit. Critical values of M/K for L_∞=420 mm and L_∞=450 mm are 0.79 and 1.11, respectively.

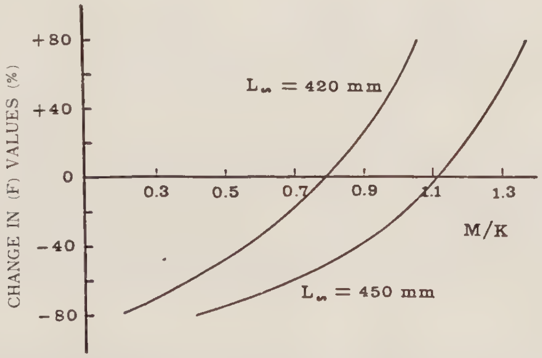


Fig. 7. Percentage changes in fishing mortality coefficient (F) needed to maximize yield per recruit, plotted against value of M/K.

Table 1. Values of natural mortality coefficient (M) calculated by empirical formula of Pauly.[19]

L_∞ (mm)	K	M	M/K
420	0.50	0.44	0.88
450	0.42	0.39	0.93

Suppose that a change in fishing effort would change the value of F in the same proportion. Judging from this result, it is theoretically expected that, in order to increase the yield per recruit, it would be necessary to increase the fishing effort if the value of $M/K > 0.79$ or to decrease fishing effort if the value of $M/K < 0.79$ for the input value of $L_\infty = 420$ mm; and for the input value of $L_\infty = 450$ mm, it would be necessary to increase fishing effort if the value of $M/K > 1.11$ or to decrease fishing effort if the value of $M/K < 1.11$.

To say whether the value of M/K of the Tsushima warm current stock is likely to be larger or smaller than the critical values mentioned above, we have attempted to estimate the natural mortality coefficient (M) to decide the possible values of M/K. Available information on the mean temperature at 50 m depth of fishing ground in the East China Sea and the Yellow Sea (KONDO[18]), leads to the application of the equation proposed by PAULY,[19] which links natural mortality (M) with growth parameters (L_∞ and K) and mean environmental temperature (T):

$$\log M = -0.0066 - 0.279(\log L_\infty) + 0.6543(\log K) + 0.4634(\log T)$$

Estimated mean temperature (T=18℃) was derived from KONDO,[18] and the estimated M obtained in this way is summarized in Table 1. It can be seen that estimated value of M/K is higher than critical value for input value of $L_\infty = 420$ mm and lower than critical value at input value of $L_\infty = 450$ mm.

IMPLICATION FOR MANAGEMENT

Based on input parameters in Table 1, further analysis was then carried out. Estimated stock size, fishing mortality coefficient (F) and exploitation rate (F/Z) were calculated and given in Table 2.

The impact of the fishery to the stock was determined by 1) calculating mean value of F/Z and 2) directly comparing the number of catch with the estimated stock sizes. The average annual loss of individuals from the stock to the fishery for both input values of L_∞ was about 45% by the first method and about 35% by the second method.

The effects of changes in fishing effort on yield per recruit at input value of $L_\infty = 420$ mm indicated that it should be possible to increase yield per recruit by

Table 2. Estimated stock size in number (mean number in the sea ; in thousands), fishing mortality coefficient (F) and exploitation rate (F/Z) based on input parameters in Table 1.

FL (mm)	Catch	L_∞=420mm			L_∞=450mm		
		Stock size	F	F/Z	Stock size	F	F/Z
150	57	85,221	0.001	0.002	82,315	0.001	0.002
160	57	85,603	0.001	0.002	82,506	0.001	0.002
170	230	85,995	0.003	0.006	82,697	0.003	0.007
180	1,206	86,359	0.014	0.031	82,845	0.015	0.036
190	1,838	86,671	0.021	0.046	82,927	0.022	0.054
200	2,011	86,963	0.023	0.050	82,975	0.024	0.058
210	3,332	87,200	0.038	0.080	82,952	0.040	0.093
220	5,398	87,284	0.062	0.123	82,755	0.665	0.143
230	11,620	86,944	0.134	0.233	82,108	0.142	0.266
240	12,128	86,221	0.141	0.242	81,058	0.150	0.277
250	14,006	85,314	0.164	0.272	79,814	0.175	0.310
260	12,248	84,341	0.145	0.248	78,495	0.156	0.285
270	18,647	82,989	0.225	0.338	76,795	0.243	0.383
280	34,870	79,953	0.436	0.498	73,439	0.475	0.549
290	65,190	73,181	0.891	0.669	66,483	0.981	0.715
300	87,696	61,556	1.425	0.764	54,983	1.595	0.803
310	79,085	47,624	1.661	0.791	41,526	1.904	0.830
320	51,300	35,724	1.436	0.765	30,248	1.696	0.813
330	36,822	26,866	1.371	0.757	22,021	1.672	0.811
340	28,520	19,519	1.461	0.769	15,382	1.854	0.826
350	20,031	13,328	1.503	0.774	9,977	2.008	0.837
360	11,531	8,706	1.324	0.751	6,102	1.890	0.829
370	6,790	5,552	1.223	0.735	3,589	1.892	0.829
380	3,780	3,340	1.132	0.720	1,949	1.940	0.832
390	1,955	1,807	1.082	0.711	923	2.119	0.844
400	937	725	1.293	0.746	311	3.011	0.885
410	117						
	Total:	Total:	Mean:	Mean:	Total:	Mean:	Mean:
	511,404	1,494,986	0.662	0.428	1,387,177	0.926	0.474

increasing fishing effort. The opposite condition is shown at input value of L_∞= 450 mm, where reducing fishing effort is necessary in order to increase yield per recruit. The fact of declinig trend in total catch during the last decade, perhaps supports the conclusion of reducing fishing effort to increase yield per recruitment. However, the decline in catch might also have been due to environmental reasons.

The fact that this stock is also subjected by the Korean purse seine and drift net fisheries (ANN[11]), and the effects of migration to nothern Japan Sea in the

summer, leads to the conclusion that the catch data used in this assessment were underestimated because Korean and nothern Japan Sea catch statistics were not included. It should be noted that further investigations should be carried out with more comprehensive data base and more accurate knowledge on stock definition as well as migration pattern of the stock.

SUMMARY

The use of material and the choice of parameters for Jones's length cohort analysis are stated. Catch data in length from the Tsushima warm current stock are picked out. Possible growth parameters are derived and cohort analysis of mean annual catches has been applied for assessing the stock size, exploitation rate and effect of change in fishing effort on yield per recruit at various input value of M/K.

Further analysis was carried out to determine possible value of natural mortality coefficient (M). With the estimates of M, it was found that estimated value of M/K for $L_\infty = 420$ mm, is slightly over the critical value, while the opposite phenomenon was found for $L_\infty = 450$ mm. Nevertheless, this evidence makes it a difficult to conclude whether it is necessary to increase or reduce fishing effort in order to increase yield per recruit.

It was noted that the catch data used in this analysis were probably underestimated and hence further investigation should be carried out. It should also be noted that these conclusions apply when only the changes in fishing effort had been given proportional effect to the changes in fishing mortality coefficient.

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マサバ対馬暖流群の体長組成によるコーホート解析

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抄 録

日本海南西海域から東シナ海五島西沖に分布するマサバ対馬暖流群について，1974年～1984年の大中型まき網漁業による体長組成を用い，JONES による方法によって資源解析を試みた.

漁獲物の体長組成については水産庁集計による大中型まき網漁業漁獲統計に基づき，銘柄別体長組成から全漁獲物の体長別漁獲尾数にひきのばして求めた.

von BERTALANFFY の成長式におけるパラメタのうち，L_∞ としては420，450mm の二通りの値を設定した．$L_\infty=420$mm の場合のKは0.50，$L_\infty=450$mm の場合には0.42とした．Mは年齢によって変らないと仮定して一定とし，M/Kは0.5～2.5の範囲にあり，最大体長階級におけるF/Zは0.8とした．資源尾数の推定値はM/K 値が大きくなれば大きな値をとるし，また L_∞ 値が大きくなれば小さくなる．加入尾数の推定値についても同様な結果になる．F及び M/K の両者を考慮して Y/R を最大にする M/K の critical value を求めると $L_\infty=420$mm では0.79，$L_\infty=450$mm では1.11である．対馬暖流群の M/K は $L_\infty=420$mm では0.88になり，critical value よりも高く，一方，$L_\infty=450$mm では0.93で critical value より低い．したがって，最大の Y/R を得るためには，漁獲努力の増（$L_\infty=420$mmの場合）又は減（$L_\infty=450$mm の場合）の二つの方向が考えられるが，この10年間の漁獲量の減少傾向からみて，Y/R を大きくするには漁獲努力を減少させた方が良いと考えられた.

APPENDIX 1

Number (ten thousands) of common mackerel caught by the large type purse seine fishery from the Tsushima warm current stock for the period 1974-1984.

FL(cm)	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	MEAN
15	7	4	8	11	2	8	1	4	8	4	4	6
16	7	4	8	11	2	8	1	4	8	4	4	6
17	31	17	32	43	10	32	6	16	34	17	14	23
18	161	89	171	223	53	171	32	83	179	88	75	121
19	245	136	260	341	81	260	48	127	273	135	115	184
20	268	149	284	372	88	285	53	139	299	147	126	201
21	441	256	477	608	153	473	90	237	484	242	203	333
22	707	436	785	962	264	769	153	400	758	388	315	540
23	1,066	737	4,963	1,354	475	1,175	286	665	1,021	570	469	1,162
24	1,545	1,217	1,900	1,827	800	1,742	488	1,064	1,312	806	640	1,213
25	1,809	1,444	2,229	1,961	1,013	1,996	647	1,255	1,340	909	803	1,401
26	1,653	1,288	1,978	1,565	1,044	1,663	574	1,059	1,071	845	733	1,225
27	2,556	2,266	2,978	2,345	1,594	2,588	782	1,625	1,655	1,300	821	1,865
28	4,907	4,149	5,395	4,529	2,741	4,844	1,558	2,998	3,283	2,432	1,519	3,487
29	9,498	7,698	9,844	8,239	5,058	8,987	3,231	5,348	6,031	4,614	3,159	6,519
30	13,142	10,611	13,182	10,416	7,412	11,825	4,442	6,693	7,882	6,584	4,277	8,770
31	12,366	9,622	11,667	8,777	6,996	10,309	4,353	5,783	6,848	6,183	4,088	7,908
32	8,093	6,156	7,442	5,677	4,290	6,631	3,053	3,970	4,373	3,915	2,828	5,130
33	5,702	4,501	5,250	3,811	3,070	4,588	2,344	3,007	2,991	2,862	2,375	3,682
34	4,229	3,489	3,964	2,819	2,266	3,404	1,928	2,496	2,247	2,195	2,335	2,852
35	2,864	2,454	2,669	1,790	1,544	2,177	1,483	1,874	1,532	1,598	2,049	2,003
36	1,585	1,343	1,454	927	841	1,118	984	1,171	889	984	1,389	1,153
37	993	864	862	512	519	654	554	652	461	521	877	679
38	538	471	509	316	279	389	305	373	262	282	433	378
39	285	258	281	174	147	221	145	185	120	117	217	195
40	156	129	134	79	75	108	68	77	47	53	104	94
41	14	11	14	9	9	13	11	9	6	8	22	12
	74,870	59,802	78,740	59,699	40,830	66,440	27,624	41,317	45,418	37,807	29,997	51,140

APPENDIX 2

Estimation of Z/K and L_∞ by method of Powell[13) :

$Z/K = 2 \times C^2/(1-C^2)$

$Z/K = (L_\infty - \bar{L})/(\bar{L} - L_o)$

where $C^2 = (\text{variance } L)/(\bar{L} - L_o)^2$; L_o is length on the edge of right hand part of the length composition curve (Jones[10]) ; L is length groups bigger than L_o, and $\bar{L}$ is their mean.

length class (FL, cm) (x)	A (f)	B (x. f)	C (x^2. f)
15	57		
16	57		
17	230		
18	1,206		
19	1,838		
20	2,011		
21	3,332		
22	5,398		
23	11,620		
24	12,128		
25	14,006		
26	12,248		
27	18,647		
28	34,870		
29	65,190		
* 30	87,696	2,630,880	78,926,400
31	79,085	2,451,635	76,000,685
32	51,300	1,641,600	52,531,200
33	36,822	1,215,126	40,099,158
34	28,520	969,680	32,969,120
35	20,031	701,085	24,537,975
36	11,531	415,116	14,944,176
37	6,790	251,230	9,295,510
38	3,780	143,640	5,458,320
39	1,955	76,245	2,973,555
40	937	37,480	1,499,200
41	117	4,797	196,677
	328,564**	10,538,514	339,431,976

x-Median value for each class median value for each class

A-Catch in number (mean value for the period 1974-1984 in thousands ; **summation of length groups larger than L_o).

B-Multiplication of mid-length and number of catch.

C-Multiplication of mid-length square and number of catch.

*-L_o $= 29.5$(refers to the lower limit of the group).

$\bar{L} = 10{,}538{,}514/328{,}564 = 32.07$

$$\text{Var } L = \frac{[339{,}431{,}976 - \{(10{,}538{,}514)^2/328{,}564\}]}{328{,}564 - 1} = 4.31$$

$C^2 = 4.31/(32.1 - 29.5)^2 = 0.65$

$Z/K = (2 \times 0.65)/(1 - 0.65) = 3.71$

$L_\infty = 3.71 \times (32.07 - 29.5) + 32.07 = 42\text{cm}$

APPENDIX 3

An example of length cohort analysis worksheet of mean length composition for the period 1974-1984 (L_∞=420 mm, M/K=0.8, K=0.5, and final F/Z=0.8).

Length Group(mm)	No. Catch (10^3)	No. in the sea (10^5)	Mean No. in the sea (10^5)	F/Z	Zdt	Fdt	Z	F	dt
145-155	57	10,802	788	0.002	0.030	0.000	0.401	0.001	0.074
155-165	57	10,486	794	0.002	0.031	0.000	0.401	0.001	0.077
165-175	230	10,167	800	0.007	0.032	0.000	0.403	0.003	0.080
175-185	1,206	9,845	806	0.036	0.035	0.001	0.415	0.015	0.083
185-195	1,838	9,510	812	0.054	0.037	0.002	0.423	0.023	0.087
195-205	2,011	9,167	818	0.058	0.039	0.002	0.425	0.025	0.091
205-215	3,332	8,820	823	0.092	0.042	0.004	0.440	0.040	0.095
215-225	5,398	8,457	826	0.140	0.047	0.007	0.465	0.065	0.100
225-235	11,620	8,073	826	0.260	0.057	0.015	0.541	0.141	0.105
235-245	12,128	7,626	822	0.269	0.061	0.016	0.547	0.147	0.111
245-255	14,006	7,176	817	0.300	0.067	0.020	0.571	0.171	0.118
255-265	12,248	6,709	811	0.274	0.069	0.019	0.551	0.151	0.125
265-275	18,647	6,262	801	0.368	0.084	0.031	0.633	0.233	0.133
275-285	34,870	5,755	775	0.529	0.122	0.064	0.850	0.450	0.143
285-295	65,190	5,097	711	0.696	0.203	0.141	1.316	0.916	0.154
295-305	87,696	4,160	599	0.785	0.313	0.245	1.863	1.463	0.168
305-315	79,085	3,044	463	0.810	0.387	0.313	2.106	1.706	0.184
315-325	51,300	2,067	347	0.787	0.379	0.298	1.877	1.477	0.202
325-335	36,822	1,415	261	0.779	0.406	0.317	1.810	1.410	0.225
335-345	28,520	943	190	0.790	0.483	0.381	1.903	1.503	0.254
345-355	20.031	582	129	0.795	0.568	0.451	1.948	1.548	0.292
355-365	11,531	330	84	0.773	0.602	0.466	1.766	1.366	0.341
365-375	6,790	180	54	0.759	0.684	0.519	1.661	1.261	0.412
375-385	3,780	91	32	0.745	0.815	0.607	1.566	1.155	0.521
385-395	1,955	40	18	0.735	1.079	0.793	1.510	1.110	0.715
395-405	937	14	7	0.766	2.240	1.716	1.711	1.311	1.310
405-415	117	1							
Total:	511,404	136,820	14,218						

Note: Calculations had been done using more significant figures.

非　売　品

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CONTENTS

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